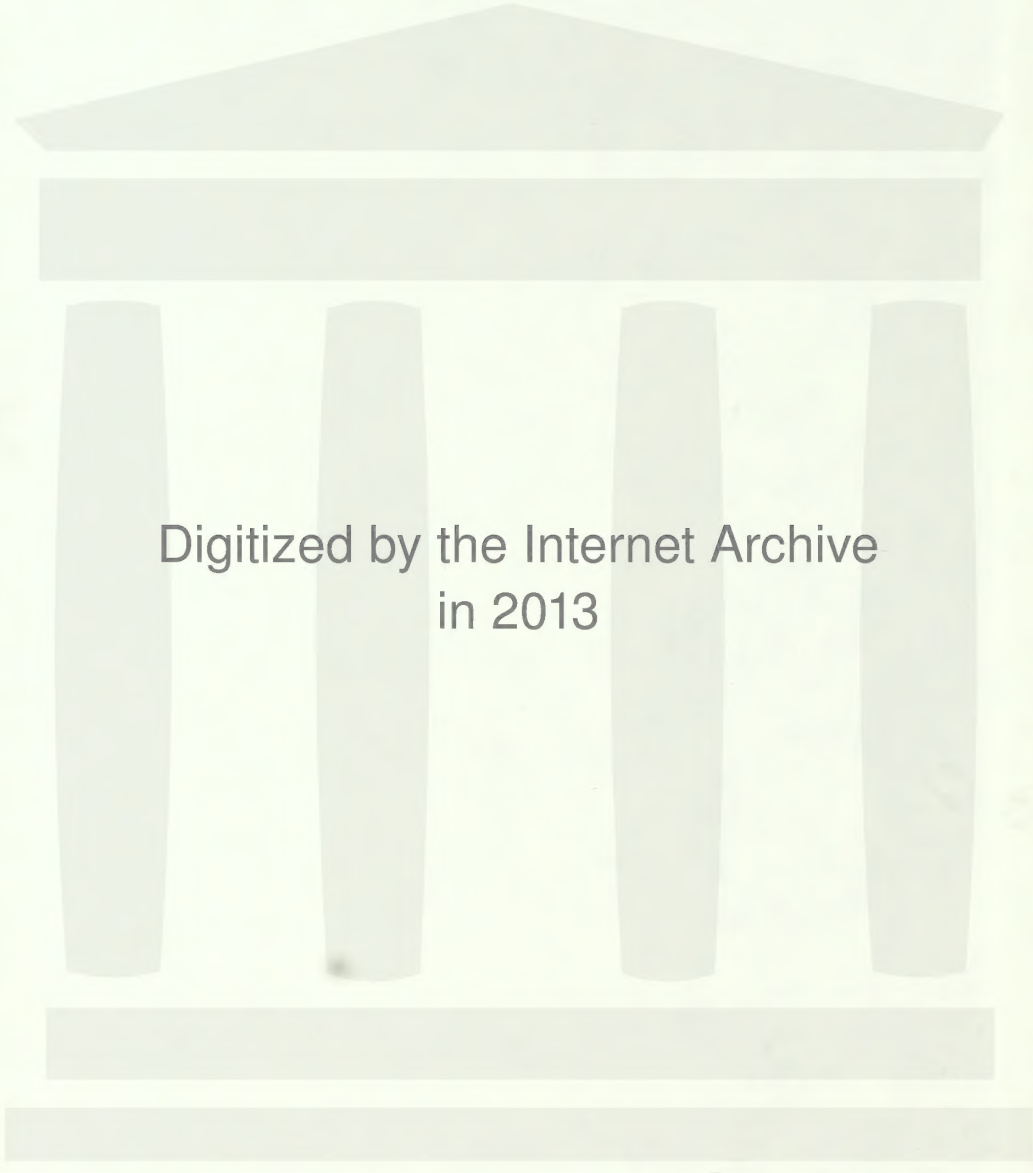


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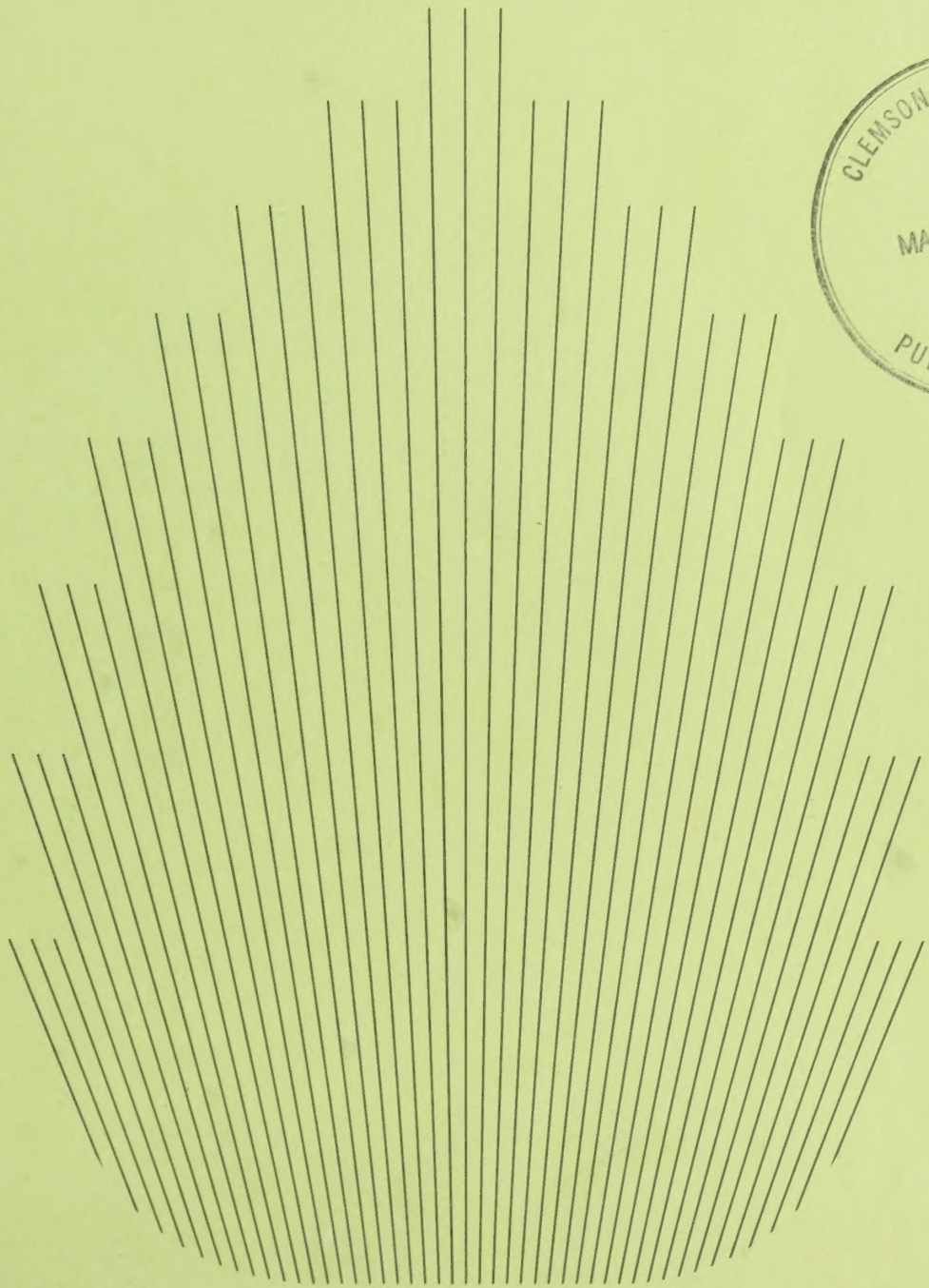
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Forest Service

North Central Forest Experiment Station

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Forestry Research Evaluation: Current Progress, Future Directions



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FORESTRY RESEARCH EVALUATION: CURRENT PROGRESS, FUTURE DIRECTIONS

Proceedings of the Forestry Research Evaluation Workshop
August 20-21, 1984
St. Paul, Minnesota

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PREFACE

This workshop had its origins in the National Planning Group (NPG) meeting in Kansas City, Missouri, in April of 1984. The forestry research leaders at that meeting agreed that the time was proper for a review of efforts made so far in forestry research evaluation. The task of organizing such a review naturally fell to the Regional Planning Group in the North Central States (RPG-2), because of the location of three key researcher groups in St. Paul, Minnesota. These are the North Central Forest Experiment Station's Research Work Unit "Methods for Evaluating Forestry Research," and the University of Minnesota's College of Forestry and Department of Agriculture and Applied Economics. The latter researchers in particular have been recognized as national leaders in the evaluation of agricultural research.

Held under the auspices of NC-RPG-2, the workshop was co-chaired by Gary Rolfe of the University of Illinois and Robert Hann of the North Central Forest Experiment Station. Hosting the workshop was shared by the College of Forestry at the University of Minnesota and the North Central Forest Experiment Station.

An effort was made to involve all researchers engaged in forestry research evaluation, with the purpose of assessing the work completed and in progress, and to consider where future efforts should be directed. To keep the review process to a minimum at the workshop itself, summaries of studies were provided by the researchers and sent to participants in advance. Thus, everyone would be familiar with the latest completed studies and also with those in progress. This left more time at the workshop to discuss the uses of research evaluations, the reasons why they are requested by policymakers and administrators, and the characteristics that make evaluations most useful. Future needs for evaluations were also discussed.

As in any gathering of interested parties, the contacts made and discussions pursued during breaks and after the daily sessions had ended were an important aspect. Because of the newness of this research effort, it was useful for researchers to find out what others were doing, what problems and opportunities they had encountered, and which studies and methods they hoped to pursue next. From this standpoint, the workshop was a success.

Current research in this area developed with impetus from several sources. First, the Deputy Chief for Research in the Washington Office of the Forest Service expressed a need for research evaluation. Second, administrators in the Cooperative State Research Service expressed a similar need. Third, researchers at the North Central Forest Experiment Station expressed an interest in pursuing this line of inquiry. Much of the credit for establishing the new Research Work Unit at North Central must go to Allen Lundgren, who laid the groundwork through his interest in the subject and his ability to engage other researchers at several universities in forestry research evaluation. The development of this area of research has been strongly aided by university researchers—those at the University of Minnesota and Duke University, in particular—and by their training of graduate students in this new area of endeavor.

Chris Risbrudt

CONTENTS

	Page
Introduction and Welcome	
Gary Rolfe	1
RESEARCH EVALUATION NEEDS AND USES	
Research Evaluation and Policymaking	
John Fedkiw	5
Discussion I	10
The Agricultural Research Evaluation Experience	
Vernon Ruttan	14
Discussion II	16
Reflections on Forestry Research Evaluation	
Richard Skok	19
Discussion III	21
RECENT AND CURRENT RESEARCH EVALUATIONS	
A Review of Current Forestry Studies	
Chris Risbrudt	29
The University of Minnesota Research Evaluation Program	
Hans Gregersen	31
A Proposed Forestry Research Evaluation Project	
Bill Hyde	34
Discussion IV	49
An Overview of the Regional Forest Nutrition Research Project	
Bruce Bare and Robert Loveless	52
Aggregate Returns to Lumber and Wood Products Research: An Index Number Approach	
David Bengston	62
Diffusion of Innovations in Forestry and Forest Products: Review of the Literature	
David Bengston	69
Summary: Evaluating Returns to Research in Timber-Harvesting Technology	
Steven Bullard	78
An Economic Analysis of a New Growth and Yield Model for Oaks in New England	
Sun Joseph Chang	79
Research Evaluation Techniques Applied to a Case Study of Short-Rotation Forestry	
Anne Fege	82
Variability in Researcher Productivity	
Pamela Jakes	91
Summary: An Examination of the Impacts Associated with Implementation of New Technology by a Major New Industry in a Region	
David Lewis	97
Summary: A Technology Assessment of Loblolly Pine	
David Newman and Bill Hyde	99
The Marketing of Evaluation Research	
Jim Olmstead	100
Summary: Estimating Productivity Changes Due to Timber Management Research in the Lake States	
Chris Risbrudt and John Benzie	110

Page

Supply Functions and Social Returns to Research
Barry Seldon 111
Summary: Productivity Impacts of Tree Improvement Research in the North Central Region
Jeffrey Stier 116
Returns to Investment in Forestry Research: The Case of Containerized Forest Tree Seedlings
Robert Westgate 117
FUTURE AREAS OF RESEARCH
The Future Direction of Forestry Research Evaluation Efforts
Allen Lundgren 121
The Future of Technology Assessments
Burt Sundquist 124
Summary: Reflections on Forestry Research Evaluations
Robert Buckman 128
Discussion V 131
SUMMARY
Workshop Summary
Chris Risbrudt 139

INTRODUCTION AND WELCOME

Gary Rolfe,
Department of Forestry,
University of Illinois,
Urbana, Illinois

I am pleased to welcome each of you to this workshop. I believe that the topic of research evaluation is one that is important today, but tomorrow it's going to be critical, both to funding of research programs that we're all interested in and to our ability to meet the research needs in the forestry arena. It's quite timely that we have a conference on research evaluation particularly related to forestry research.

Some similar research evaluation studies have been done in agricultural research and I think that they have traditionally paid off. Research evaluation studies in relation to forestry have paid some dividends as well. So, the short of it is that I think this is a good conference to be at. We can make some real progress today and tomorrow and I believe it's time that we considered the topic of research evaluation and make some plans for being ahead of the game.

Often, in quite a few research areas, we find ourselves in the situation of immediately responding to an emergency or to a need for research or for planning. It's time we get ahead of the game, so that we anticipate some information needs over the long run and do some planning that will allow us to effectively respond. Research evaluation is one tool we have to help us in that process, and it's a very important tool.

Research evaluation is especially important because it can help us to be better researchers. In the next few years that is going to be critical, because, as all of you know, we are seeing an erosion of formula funding or block funding for different research areas, including forestry. I think that trend is going to continue and we're going to see an increase in the competitive grant approach to research funding. To be competitive as scientists we are going to have to be on top of the game. That means we will have to know what we're doing, why we're doing it, what objective we're going to reach, how soon we can get to that objective—and we will have to do that all in a cost-efficient manner. So research evaluation can benefit us in these areas. It can help us do a better job of productive research, it can help us to be better research planners, and it can help us reach our objectives in providing good, hard forestry research results in a much more cost-effective way. I think that's the real question that we're going to get down to in the end. How much can you do for how little of the resource? That's always the case, it has always been the case, and it's going to be much more important in the future. So, I don't think I can say too much about the importance of research evaluation.

Getting beyond the individual researcher, research evaluation studies are important at the State and Federal levels. The people who are working in that end of the system have to be able to demonstrate definitive data which support what they're doing in terms of productivity, in terms of the results being useful, and in terms of cost effectiveness. One way they can obtain the information they need to support these arguments is through good studies, especially good evaluations of research programs. In considering funding both at the individual researcher level and at the State and Federal level, research evaluation studies can genuinely pay off.

In addition to the funding aspect, I think that at the National and State level research evaluation studies can help us identify gaps in our research data base, isolate research areas which need more attention, and support and justify moving our research program in appropriate directions.

There are several reasons for research evaluation studies, and this afternoon as we discuss these studies I'm confident we all will agree that this is a good time to consider research evaluation and how it can lead to more effective research planning. This particular conference came about as a result of the RPG-2 Planning Group meeting in Kansas City last year. Unfortunately, I was unable to attend, but as the RPG-2 co-chairman with Bob Hann, it was our responsibility to organize this gathering to look at research evaluation. It worked out quite well, because I really didn't have to do anything at all except sign my name on a few letters. The North Central Forest Experiment Station and the University of Minnesota actually did the work in getting you all here and making this conference happen. I think the fact that we're here and can make some progress over the next day or so is very important.

The objectives of this workshop are twofold, at least, and I'm sure that over the day and a half that

we're going to be here we'll identify some new areas that we need to discuss as well. The first objective is to discuss the current uses of research evaluation studies and to project the sorts of research evaluation needs that we may see in the future. What types of things do we need to do in the long run to really be ahead in our planning process? That's a very important objective so we'll start off taking a look at what we're doing now. Hopefully, we'll have some good discussion with everybody involved as to where we need to go with research evaluation studies. The second objective of the workshop is equally important: To bring together scientists who are currently doing research evaluation studies and allow them to share with administrators and other scientists the purpose and objectives of their program and the results that they have obtained to date. Looking at the study summaries, there is quite a bit of common ground, but we can all learn by thinking about different approaches and different techniques.

Certainly research evaluation has some new tools that can be used over the coming years. The computer tools that are available will help to more efficiently do these types of studies. We have a significant opportunity over the next day and a half to talk about this important subject. We have the people here who can help to define and plan a long-term program of research evaluation, which we very definitely need in the forestry research area.

RESEARCH EVALUATION NEEDS AND USES

RESEARCH EVALUATION AND POLICYMAKING

John Fedkiw,
Associate Director,
Office of Budget and Program Analysis,
Office of the Secretary,
U.S. Department of Agriculture,
Washington, DC

It is rewarding to be a part of this forestry research evaluation workshop because so many evaluators are participating and much evaluation is going on, something I have supported for many years. There is a serious interest at both the managerial level and the research analyst level, and I note from the advance materials that the forestry research project we are here to review is beginning to have useful and notable first fruits. Chris did not give me any specific instructions or topic to address.

He leaves me feeling like a first lieutenant at point with no discernible targets and no clear orders. From that standpoint, some background views on the need for this evaluation effort seem to be an appropriate place to begin. After that, I will have comments on how we got into program evaluation, the usefulness of evaluation results, new information priorities, and the value and use of the evaluation results in research planning and decisionmaking. I will approach my subject with a broad view to give you some feel for the environment in which this type of information is used and how it is applied.

THE NEED FOR RESEARCH EVALUATION

As a start on the question of the need for research evaluation, I would like to take you back to the beginning of beginnings—the story of the Garden of Eden and of Adam and Eve, our first progenitors. Eden is a place without any demand problems, without any supply problems, no technology needs, and no new knowledge needs. It didn't last. It was not long before our progenitors violated certain basic principles and they were evicted, with a divine direction: "Henceforth, you shall work by the sweat of your brow." Note the great symbolism in the choice of words—by the sweat of your brow and not our backs. It doesn't take much whimsy or imagination to take that divine command as the beginning of research and a blessing of goodness on all research and all researchers. In that context, research can be seen as truly the first profession. Claims for the first profession among the denizens of the "red-light district" are truly apocryphal. After all, with only Adam and Eve, there could be no factual basis for the latter claim. It takes three to make a triangle.

So, almost from the very beginning, we had to find out for ourselves how to provide for our demands, produce our supplies, and develop all the technology to serve 4 billion progeny today and, in the not-too-distant future, 2 billion more people. That little story reflects the goodness of research and researchers, and the need for evaluations. What and how much is research doing for the progeny? There is divine goodness in what we do, but the value of what we do is judged by the progeny among its other needs. I felt the need to address the question of goodness because when we first addressed program evaluation for forestry research in a formal way at USDA in 1966, it upset a lot of people. I remember one researcher in particular. He is now one of the strongest supporters of program evaluation. In 1966, however, he saw it differently. During an extended dialogue about the desirability of program evaluation, he suddenly stopped and said, "John Fedkiw, you don't appreciate the goodness of research." And there has been more than one researcher who has repeated that view over the years.

Let me bring the story down to earth by paraphrasing the Deputy Secretary of Agriculture's views from a dialogue on the forestry research budget last Thursday. The point had been made that forestry research had declined 17 percent in the last few years and that agricultural research had grown significantly. The Deputy Secretary responded with an analogy, but his point was, "we believe in the goodness of forestry research but when I speak about research allocation, the people ask me, what are we getting for the investment?"

The Assistant Secretary for Natural Resources and the Environment has been making tradeoffs among forestry programs at USDA for several years.

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They unambiguously indicate a perception of low productivity for research at the margin compared with other alternatives for increasing forest productivity, timber supplies, and other resource supplies. There is no other way to interpret it. His views are not explicit about where those margins are within research, so he leaves it to the Deputy Chief for Research in the Forest Service to make those decisions.

One area, however, has been highlighted, and that is hardwood management research in general. Inventories have increased 50 percent since 1952, because we have been harvesting only half of the growth. These inventories will continue to grow for 20 years or more even as we increase the harvest of that hardwood inventory. The question is, how much has hardwood management research contributed to that abundance? How critical was the technology in the past to achieving the current abundance? How critical is it likely to be for future supplies? I don't have clear answers for these questions. One is left to make a practical judgment on the basis of the availability and outlook for hardwood supplies and prices. There is no question about the goodness of the research in this area, but goodness does not provide sufficient guidance for a practical answer to the research allocation question.

One can cite similar critical questions in other segments of forestry research, as well as some specific real benefits and contributions. It isn't all one-sided. The bottom line is that we have done some good, but we have little quantitative measure of how much good. There also appears to be room for improvement. It's a mixed bag. It's confounded by the fact that we do not have overall measures of forest management productivity itself, the contribution that research makes to it, or the criticalness of research to future productivity. Conceptually, there are answers to these questions, but we don't have any relative measures.

There is no general policy question about the intrinsic goodness of forestry research or about the need for a reasonable level of scientific capability in this area. The practical issue of need is concerned with resource allocation decisions at the margin.

To cap this general note on the need for research program evaluation, let me cite an agricultural viewpoint from the first paragraph of the preface to the Proceedings of the 1969 Symposium on Resource Allocation in Agriculture Research. That was about 15 years ago.

> "In any area of man's endeavors, it is good for him occasionally to take stock of where he is at present, and what he has accomplished. With this new perspective, he then can more effectively design and carry out his future pursuits, whatever they may be. This volume is the result of such stock taking; in this case, the focus has been on efforts to evaluate the productivity of agricultural research and attempts to plan and direct such research in and by public research organizations."

THE BEGINNING OF FORESTRY RESEARCH PROGRAM EVALUATION

In my experience, forestry research program evaluation as a formal activity began in the mid-60's with Planning, Programming, and Budgeting (PPB). This was the Johnson Administration's effort to allocate resources more efficiently to nondefense programs, governmentwide. The key tools were *ex post* evaluation of program effectiveness in providing net benefits—that is, benefits to national welfare—and *ex ante* analysis of the benefits and costs of new initiatives.

The first application in forestry was *ex ante* analysis of the benefits and costs of southern pine genetic improvement research. The results were endorsed by the Department and sent to the Office of Management and Budget (OMB) as a credible analysis and projection. They were used explicitly in justifying the tree improvement segment of the research budget and they were highly successful in doing so. I remember the Deputy Chief coming to me after the final budget marks were out about a month later and saying that the research budget outcome that year was a historical first. He was not sure about all the reasons for it, but the *ex ante* analysis was a part of it. It was the first time the rate of increase for research exceeded the national forest allocation.

Shortly after that, the Forest Service assessed the costs and benefits of a selected technology in each major research area from utilization down to forest protection, including insects, disease, and fire. This, I believe, was *ex post* evaluation. The results showed a very high rate of return for forest products and utilization research, and relatively low marginal or submarginal rates—depending upon what you consider the capital cost at that time—for both fire research and insect and disease research. That pattern suggested that research efforts which improved or developed new products or reduced their cost of production were highly productive. This is confirmed in one evaluation project we are reviewing today—the work Hans Gregersen has completed on lumber and lumber products research. It shows a 36 percent rate of return on the marginal research investment.

Research benefits that are long deferred appear to have a relatively low social value. That has some implications for short rotations, improving species

substitutability, and removing the dimensional requirements for large trees. Some of the most successful research has worked in those directions. Most of the work that has achieved those kind of results, however, has been done in utilization areas. We have learned how to use smaller trees; we have learned how to use hardwoods in place of softwoods; and we have learned how to use thinning to shorten rotations and increase tree size. Your current short-rotation research evaluation project covers one initiative that addressed all three purposes simultaneously. That research involved substitution of a relatively unused species (sycamore), a short rotation of 3 to 8 years, substitution of a hardwood species for softwoods, and some reduction of the dimensional requirement for pulpwood.

There was a long lull in forestry research evaluation after that study of comparative productivity, about 5 or 6 years. Then, in the middle 1970's, a General Accounting Office review of the 10 most productive projects identified by Forest Service research and a similar study by the Department's Office of Audit revealed some serious shortfalls in the transfer of research results, their operational feasibility, and their utility. These findings led to specific efforts to increase the effectiveness of technology transfer and to seek more effective feedback from potential users at all stages of research planning, execution, and transfer of results. These evaluation efforts were followed by a broad Forest Service initiative to develop criteria for defining allocation priorities for future research as a part of 1980 RPA. It did not deal with the current base program, but recognized it would turn over in the future and would be part of the priorities. There also were some quick and dirty *ex post* evaluations for selected results of completed research. The latter were not and could not be generalized. Some of the evaluation work was questionable.

Policy decisions on the 1980 RPA research program responded favorably to the structured analytical commitment and effort. The policy officials felt the Forest Service was making a genuine effort to allocate resources in a way that would maximize expected benefits. A 5 percent rate of funding increase was proposed. The emphasis was on increasing national forest productivity and on a number of emerging problems such as acid rain and desertification. The Department officials strongly withstood efforts of OMB to reduce the proposed rate of growth. It was challenged because it was higher than the rate of growth proposed for the Defense Department in that year. Shortly after the 1980 RPA decision was finalized the North Central Forest Experiment Station's research evaluation project was established.

USEFULNESS OF RESEARCH EVALUATION RESULTS

My comments to this point have already provided some views on the usefulness of research evaluation. Here, I'm going to offer a more comprehensive and structured assessment. I will cover *ex post* and *ex ante* evaluations separately.

Ex post Evaluation

Ex post evaluations are most useful and valuable where they address large program aggregates or subaggregates. Individual project evaluations have little utility or value in decisionmaking. Individual completed projects are historic events with fixed costs, and unlikely to be repeated again. Such evaluation results cannot be used as sufficient measures of the general productivity of the research programs they represent. Results often vary widely, from deeply negative to highly positive. However, we seldom will evaluate the deeply negative. The results may be additive if they are truly representative and if they are based on consistent assumptions, methodology, and benefit measures and unit coefficients. I would like to illustrate the importance of aggregate research evaluations or the evaluation of large subaggregates from experience in agricultural research.

The most important single bit of *ex post* evaluation information about agricultural research is the understanding of how much research has contributed to the overall productivity of agriculture, total food and fiber supplies, farm and consumer price levels, and general national welfare. I can illustrate this best by quoting a statement Secretary Block made in 1981. It reflects both the understanding and knowledge that policy people have of agricultural research productivity in the *ex post* sense and the value of that information:

> "During the 1960's, American agriculture experienced a tremendous advancement in technology and research. These factors allowed agriculture to produce more abundantly and far more efficiently than at any time in history. In fact, so much more was produced that it caused a price depressing oversupply...
>
> "Since 1950, our agriculture increased its output by nearly 70 percent while increasing input by just 4 percent.
>
> "Even more significant is the fact that today agriculture is the largest net contributor to our balance of trade with a surplus reaching toward 30 billion dollars."

That is a clear, strong perception of the value of agricultural research. In 1965, during the early days of PPB, we made a similar assessment. We found we were producing our agricultural output in 1965 with the same real cost of production that we had used to produce the output in 1950. Both domestic consumption and exports were substantially higher in 1965 than in 1950.

Not all improvement in agricultural productivity can be credited to research. There is systematic analysis, however, that suggests that about a third of the growth in this productivity can be attributed to public investments in research and extension. There is much documentation of agricultural research productivity and its benefits in the aggregate and for major subaggregates. It is widely understood and applied. There is also confidence that agricultural research can deliver the desired results with an acceptable probability of success and a relatively small increase of funding. That's an understanding shared by the U.S. Department of Agriculture's Director of the Budget, and he expresses it as his understanding of the perception of the Department's policy officials.

Nevertheless, that has not been a guarantee for unqualified public investment. In the earlier part of the 1960's, Federal agricultural production research was being continuously recommended for reduction or no increase in budget reviews. Its actual funding by Congress reflected those recommendations through the mid-1970's. Production research was seen as contributing to the growth of surplus commodities and record federal costs to reduce that surplus.

Agricultural productivity improvement was observed to slow in the late 1960's. It was also observed to slow in the 1970's, after a sharp increase in 1971. These patterns may or may not have been a response to the slowdown in research funding. Nevertheless, these perceptions, combined with the sudden and rapid expansion of export demands after 1972—mainly, grain exports to Russia—raised new concerns about the productivity of agricultural research. Several studies on the effectiveness of agricultural research and on new priorities for an expected long-term rising trend in world food demands and U.S. exports were commissioned, primarily by Congress. A great deal of congressional attention was focused on means to improve both agricultural productivity and related research productivity. This resulted in identifying new research priorities, emphasis on basic research, and an increase in Federal funding which has continued through this Administration.

The important point of these comments on agricultural research is the understanding of how important agricultural research is to the productivity of agriculture. That is basically an *ex post* evaluation understanding. There is a widespread understanding of the linkage between agricultural productivity, supplies, and prices and agricultural research productivity.

There are good measures of agricultural productivity and they are updated annually. But in forestry we don't even have a good measure of productivity as an aggregate measure for the country or for a major subregion. That may be an information priority you will want to think about. It seems to be a fundamental need in evaluating how forestry research relates to total forest productivity.

Measures of research productivity in agriculture are less regular and generally less adequate for year-to-year assessments. Nevertheless, there is enormous public and policy sensitivity to that known linkage with the productivity of agriculture. Congressman George Brown has been concerned about long-term agricultural productivity and commodity supply as they relate to world food demands and welfare, as well as U.S. welfare. Other members of Congress have concerns that are more local and related to farm income in their States and districts, and to short-term results and applied technology. For example, during 1966-1976, when funding for Federal research was flat, Federal grants to States for agricultural research continued to rise, and State funding for State agricultural experiment stations actually accelerated. The States did respond, including their representatives to Congress, to funding of State-oriented agricultural research.

Thus, the agricultural productivity research linkage exists not only at the national level, but extends to the State level wherever agriculture is a major economic activity and agricultural productivity is an important determinant of State comparative advantage and economic welfare. However, there is a difference in Federal and State concerns and it is epitomized by an anecdote about the USDA's Deputy Secretary for Agriculture. When he received a report recently that a land grant university in a leading milk-producing State had found a way to increase milk production per cow significantly with a simple injection, he responded that it was "UDDERLY terrifying research!" Given the concerns for surplus milk and cheese and the huge costs of USDA purchase programs, that assessment conveys more than a sense of humor. Obviously, milk cow productivity does not have high priority for Federally funded research.

The concerns are not always generalized across the board; exceptions are seen. Congressman Brown has been particularly strong in trying to get the

USDA to be more specific and more complete in *ex ante* analysis of research targets to increase productivity.

In contrast to agriculture, in forestry there is very little clearly known or understood in quantitative terms about the short-term or long-term linkages between forest productivity, supplies, prices, and the productivity of forestry research. The problem is more complicated than a lack of measurement of research productivity. We do not have any general measures of forest productivity trends for the total sector or its major subaggregates to serve as a focal point for concerns about research productivity. More than that, we do not have any measure of the productivity of controllable forest management inputs and how they affect total productivity, and how critical forestry research is to the productivity of those management inputs.

These last observations provide a broad perspective on where we are with forestry research program evaluation in the *ex post* sense, and offer a broad target for where this evaluation research should be headed. Despite the foregoing views and general assessment of forest research effectiveness, there is a general understanding among policy officials that forestry research does contribute to short-term and long-term forestry productivity, even though it is not well quantified. They are aware of case examples, and in general tend to extend the agricultural research experience with respect to productivity impacts to the forestry research sector. There is a commitment among policy officials to maintain an effective level of scientific capability in forestry research. Policy officials also respond incrementally to new problems and opportunities of national significance. One that was of particular interest to the Deputy Secretary in 1984 is, "Where are we at with acid rain; do we need to do more in identifying and understanding that problem?"

Ex ante Research Evaluation

In contrast to *ex post* evaluation, *ex ante* research evaluation is most useful and valuable when applied to specific technological problems or technology targets. It is probably the strongest option for critical justification of research projects to develop new technology for production purposes. It probably has little value for research issues where the major concern is uncertainty and the major purpose of research is to define the dimensions of a problem or identify viable options for amelioration of a problem. Acid rain, of course, is a case of this type. An example where *ex ante* evaluation was usefully applied was the 1960's evaluation of the potential net benefits of southern pine genetics research which I cited earlier.

CONCLUDING REMARKS

I have come to the end of my remarks and will close with the common saying among informed staff people concerning the evaluation and review of annual program proposals and budgets. The productivity of a program is and will be evaluated in each budget year, empirically or judgmentally, as well as comparatively, whether or not a systematic quantitative evaluation is available. When quantitative evaluation data are available, they will be taken seriously, as well as critically.

Insiders from OMB have said more than once that the improvements over the years in evaluation or analysis for program justifications have made their task much more difficult to perform. My response has been that they are mistaken: it's much easier to do. But it is more difficult to reduce justifiable initiatives supported with sound analyses, even in the face of budget ceilings.

The general philosophy of research is that systematic, verifiable, quantitative analysis is superior to empirical observation and judgmental evaluation. That type of analysis also is more certain in *ex post* measurement than in *ex ante* forecasts.

The support of research program evaluation, both *ex post* and *ex ante*, is a proper, legitimate function of program administration and management. It rests primarily with the managers who assess the effectiveness of program aggregates and subaggregates and determine priorities for resource allocation. Evaluation results can be a powerful tool for research managers because such results provide a basis for disinterested judgment in allocating public revenues to enhance national welfare or State welfare. It can be particularly helpful in the face of the "thousand hands" on the inside and the "thousand hands" on the outside, who are annually trying forcefully to help managers divide the pie. But it will take courage to use that evaluation tool openly and straight forwardly. A large volume of credible evaluation results both in *ex post* and *ex ante* mode is probably the best source of such disinterested fortitude in resource allocation.

DISCUSSION I

DENVER BURNS

I would like to ask a question concerning timeliness of evaluation. Agricultural production evaluations are now many years old. The ones that have been done in forestry will age quickly. How relevant is that timeliness to the usefulness of evaluations for policy?

JOHN FEDKIW

I think the relationship and linkage between agricultural research and agricultural productivity has been established, quantified, and updated regularly. The quality of the evaluations has also improved each time. The last comprehensive evaluation of agricultural research productivity, including extension, that I'm familiar with was done by Bob Evenson about 1980, at Yale University; he was formerly with the University of Minnesota. His finding was that about 50 percent of the agricultural productivity could be attributed to investments in research, extension, and the education level of the farmer.

LYNN MAISH

I think timeliness depends on which type of evaluation is made. John's main point is to get this understanding of the linkage between productivity and research. That's the sort of background information that is useful in policy decisions. Once you achieve some broad understanding of that basic knowledge for policymaking, timeliness becomes more important in smaller decisions.

DENVER BURNS

I guess my real interest here is at what point did it pervade the policymakers' consciousness that agricultural research was a good thing? For agriculture, did that start and stop with hybrid corn, or has it been the recent spate of articles? There are many good cases in forestry, and yet they don't seem to have any lasting effect. Part of that problem is that we have not expressed research effectiveness very well.

JOHN FEDKIW

The very beginnings of the U.S. Department of Agriculture in 1862 were concerned with improving productivity by distribution of better seeds. That, in a sence, was an extension program. But there was a research program that also began then. It was a Federal research effort. Later on in the 19th century the public decided there ought to be research at the State level also. That led to the formation of the land grant research program and system. From about the middle of the 19th century up to about 1910 quite a bit of research was done. U.S. productivity in agriculture did not appear to be increasing and it became the source of great concern in the early years of this century. There were discussions among the agricultural scientists and the policy officials about what to do about it. One of the focal points of that dialogue became, "We have got to get some way to take this technology and get it to the farmer." There was a Federal initiative for that, and there was also a State initiative. It worked out that the State initiative would put a technician in each county to work with each farmer. One-to-one contact that could transfer that technology became the extension legislation, the Smith-Lever Extension Act. A contract was written up that the States will administer that law, carry out and execute the extension, while the Federal government will only administer the legislation in a broad, general way. Once that was put into place, it had great impacts on the transfer of agricultural technology and productivity improvement. There were some really great assessments of those impacts from 1915 to 1955, or 1960. There are high marks for that extension and agricultural research linkage in technology transfer. Agricultural research wasn't going any place until extension got linked into it. Today that linkage may not be quite as effective as it used to be, nor perceived as having the same value. Part of it results from the evaluation work that has been done. Perceptions change. For example, in the 1960's and early 1970's, there wasn't any great support for agricultural production research because of the crop surpluses. That has now changed because of the outlook for world demands and the need to build up supplies and to remain competitive on a price basis in world markets.

DENVER BURNS

Perceptions do change, for we're just now seeing forestry move from land-based towards technology-based management. The last of the forest lands are being allocated to various uses. That parallels what occurred in agriculture when lands were no longer available.

JOHN FEDKIW

I don't think we really understand what we're trying to do in the aggregate with respect to forest resources, productivity, and production in hardwoods versus softwoods. I think we've got an abundance of things working in different directions. In my view, the work that has been done in wood products research by industry, the Forest Service, and universities in some cases is equal in productivity to agricultural research. The story is probably equally spectacular in terms of keeping the costs of production for wood products down and supplies relatively abundant. Although real increases in stumpage prices may have obscured some of the benefits in the case of softwood products, we have just as spectacular a story to tell there as we have in agriculture.

When you add to production or reduce losses, you are saving the last timber that will be harvested, so to speak, from the current inventory. This was recognized when we were doing mountain pine beetle control. There we spent quite a few million dollars and finally decided it was not cost effective. We were trying to save stands that wouldn't be harvested in 80 years anyway. There was an effort in western white pine blister rust control that did not work. On the other hand, we've got southern pine plywood technology, which was developed at the Forest Products Laboratory. We've got waferboard. We've got hardwood pulping. We've got press-dried linerboard from hardwoods coming as a substitute for softwoods. Softwoods are scarce. Hardwoods are abundant. There's quite a bit going on in this forestry world, in terms of efforts to increase productivity, save resources, and things like that. Some very gross evaluation work can be quite revealing in this area, because it has never been put together in a systematic, analytic way.

ALLEN LUNDGREN

That raises a question, John. We're just getting started in forestry research evaluation, according to my perception of the field. We are mainly doing some individual case studies. How useful is that kind of information in building a perception of forestry research productivity among policymakers compared with comprehensive studies—aggregates or subaggregates of forestry research which may be beyond us at this point?

JOHN FEDKIW

I think the piece that was done on lumber and wood products is a good start on evaluation of subaggregates of forestry research. But you have plywood, you have hardwood substitution for softwood pulpwood, and a whole set of projects to extend the existing wood supply by making low quality timber and species substitute for very high quality timber and species through changes in conversion and utilization methods and technology. Sum these changes up and see what technology has done for us in this area with respect to wood supplies. What would our wood supplies have been if we hadn't had the new technology? We would be building houses out of brick, sand and glass, or something like that if we hadn't had that technology. I think it has been an enormously great benefit. I don't think we can show the same thing in other areas of forestry research. It is not that they are unimportant and not that we shouldn't continue to do work in management research, protection research, and other areas, but we ought to assess the expected net benefits when we expand or allocate research funds beyond the level for maintaining scientific research capabilities.

DAVID LEWIS

John, in the area of natural resource policies, does part of the process involve looking at new technologies, as opposed to other policy instruments for achieving whatever stated goals you might have?

JOHN FEDKIW

For the 1980 RPA, we had a list of 14 issues that were prepared by the Forest Service and presented to policy officials. There were two issues added by policy officials. One was a request for an assessment and projection of the supply impacts that can be expected from emerging technology. They were not looking for a certain solution. They wanted to understand the supply potential of the visible, emerging technology. The Forest Service economists made such an assessment working with the researchers, and a lot of the results were judgmental. Like Vern says, you have to talk to scientists to get some really good information, in making ex ante *projections. It is my recollection that the economists and scientists judged that the emerging technology would reduce the demand for supplement timber supplies by 8 million board feet by 2000, over and above the 1980 RPA assessment estimates. That is a large increase in supply in 20 years. But no one in the Forest Service came forward and said, "We need money to do this." We didn't ask for more, although it may be one of the reasons we got the 5 percent increase. I do not recall that the priorities for utilization research were very high.*

DAVID LEWIS

So are you saying that we dropped the ball ourselves in a sense?

JOHN FEDKIW

I don't think the issue was pressed very hard, and I don't understand why. I've gotten involved in examining the credibility of some of this technology. We're looking at plantations today and sorting out what the results have been since genetically improved stock has become widely dispersed. There is a project underway to evaluate the on-the-ground benefits of the tree improvement work as it is beginning to show up in young plantations. This tells us that what we assumed in the 1960's for southern pine genetic improvement may have been high, reflecting what can be expected on managed research plots as opposed to outplantings with less oversight and care. So the actual productivity improvement may not be as high as projected in the ex ante *evaluation. Nevertheless, the actual benefits achieved are probably worth substantially more than the research costs. I would like to see a similar evaluation of the genetic research at North Central. I think that's a piece of work that is ready for assessment.*

ROBERT BUCKMAN

I don't dispute the notion that the biggest gains in forestry have come from utilization research, but I also have the feeling that there is a very strong neglect of what the biological contributions have been. The utilization gains tend to be easily identifiable, easily described...something tangible and concrete that you can hold in your hand...structural flakeboard, press-dried paper, things of that sort. Whereas a lot of the gains in biology have been incremental and lots of people have made small contributions, but in the aggregate the contributions are enormous. The resurgence of the forest resources in the South in my estimation is the Cinderella story of forest conservation in the world, and yet it is a story that is not well told at all. And it began with education and some fairly simple technologies, such as fire protection, getting hogs and livestock off the range, etc. Today we are approaching the time when the South will supply half the forest products of the country. It is a story in biology. It started out very simply. But with thousands of small increments in the nurseries, in planting practices, in tending, in insect and disease control and fire control, we have made enormous contributions. The same is true right here in the Lake States. I think we need to give more attention to the biological side of technology.

JOHN FEDKIW

I agree that there have been some significant things done on the biological side of forestry. Part of the work that impressed me was led by Mann in the Southern Station on tree seedlings, planting stock improvement, and grading. I was rather impressed with the kind of things that were coming out, because they led to better survival rates and lower production costs and also better growth performance because of a better grade of seedlings. That was a very important piece of research that made a big difference in the productivity of and the interest in tree planting. I am aware of some of these things, and perhaps in some species they have been important. Southern pine would be one. Where fire is concerned, probably the biggest contribution came from the institutional and behavioral changes that took place in the courts and among farmers and other people.

ROBERT BUCKMAN

But you made the point earlier that Evenson makes that you can't separate education from science.

JOHN FEDKIW

He sorted out the increments of research, extension, and the educational level of the farmer. I believe he came to the conclusion that while extension was a smaller investment it was as productive as the research itself, using multiple regression methods. Returns to extension were highly dependent on the level of research investment, and returns to research were modestly influenced by extension according to that analysis.

ROBERT BUCKMAN

The question that has been around before, for me and for my predecessors, for as long as I have known is, "Why are you doing this when the industry should be doing it?" This goes way back before this Administration. We had a very formal inquiry on that issue from OMB a couple of years ago. We made out a set of criteria that should guide Federal investments in research. One of them had to do with backstopping regulatory programs. There were about six criteria. We did a 100 percent assessment of our portfolio of research studies in the Forest Service to identify any possible industry-type studies, and then we followed up with a series of telephone interviews on top of that. We've been so sensitive to that issue, that I really would like to think that we positioned ourselves, by and large, in areas where the industry itself would not do the research. About 80 percent of our studies are in the nonproducts field—they are in biology, protection, inventory analysis, etc. And about 20 or 22 percent are in the products and engineering field. In the products and engineering field we try to deal with things that have a consumer interest or that backstop Federal land management programs, have a regulatory context, or a long-term basic, or a major speculative or risky, aspect. If that research is successful, if

those kinds of studies, the basic research or the risky long-term research targets are successful, they ultimately lead you to the point where it is useful. The thing that I objected to most in the OMB study was that OMB staffers tended to treat this research segment, which ought to be a continuum, as a discontinuity or to introduce a discontinuity into it. When the research approaches utility then you drop it and somebody else will pick it up. I don't happen to agree with that. This ought to be a continuous process. Those of you who have been to the Forest Products Laboratory in Madison, WI, have seen one, two, or three emerging technologies like press-dried paper, which could be a very big contribution in the near term. When the utility of press-drying became evident, we invited industry to look over our shoulder and talk about it. That is a model of the way we ought to work with the private side. The industry said we need to know certain things before we will make the first investment. We built a small pilot plant machine. We built a high-speed simulator that would mimic production speeds, pressures, and temperatures. About the time we finished with that the industry said we had carried this far enough. We essentially dropped that as a main line of work and moved off into other technology targets like recycled fibers, and things of that sort. Avoidance of duplication of industry research is an issue that we have been extremely sensitive to. I would like to think that relatively little of our work is in the product development area. Now there is one exception; in some of the areas of economic downturn, such as the Appalachian area, we are doing some work that gets fairly close to application. I have a suspicion that if we didn't do it nobody else would. Things like upgrading hardwoods so that they can be better used in furniture stock and things of that sort.

THE AGRICULTURAL RESEARCH EVALUATION EXPERIENCE

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The reason that we're interested in research evaluation is because we want to allocate research resources. I will discuss some of the principles that are involved in thinking about the allocation of research resources. These are the issues upon which we want to bring analysis and judgment to bear in our research evaluation studies.

Whenever we allocate a research dollar, we're always either explicitly or implicitly answering two questions.

The **first** of these questions is: What are the possibilities of advancing knowledge or technology if resources are allocated to a particular commodity, problem, discipline, or geographic region? The interesting thing about this question is that to get a good answer, one must ask those who are at the leading edge of their discipline or profession. In any given area, there are relatively few researchers who can imagine what can be done beyond what is being done now. In answering this question, the intuitive insights of economists, planners, and administrators are not very much help. We have to extract that knowledge from the best scientists in the various fields.

The **second** question is: What will be the value to society of the new knowledge and the new technology if the research is successful? Dr. Richard Bradfield of Cornell, who was one of the world's great soil scientists, once commented, "There are thousands of interesting questions—and some of them are important." It seems to me this captures what we're concerned about. Whether we employ formal analysis or intuitive judgment when we allocate research dollars, part of the question we must answer is, "What's the research worth to society?"

I argued above that the intuitive insights of economists, planners, and administrators are not very useful in telling us what can be done. The intuitive insight of scientists, or of administrators who used to be scientists, is not very good at telling us what things are worth. We must attempt to answer both the question of what can be done and how valuable it is to do it. We can approach the problem at many levels of sophistication. But if we keep in mind that these are the questions we're trying to answer, even in areas that we have to approach intuitively, the chances are that we will be able to make better decisions.

Let me note three approaches that are commonly used. The model frequently used in making research resource allocation decisions might be called the parity, or congruence, model. This model is implicit in the question, "Did I get my share?" Just for a definition, if the percentage of dollars spent on, for example, maize research, is equal to the percentage of the value of commodity production contributed by maize, the ratio is 1.0. Nobody really believes that the ratio should be 1.0. But in discussions about the allocation of research resources, the congruence model is frequently implicit. One can calculate congruence ratios by commodity—for example, maize. One can do it by geographic area. Some of you may know of a study published by the University of Wisconsin that concludes that the Midwest doesn't get its share of the Federal research dollar. One can also calculate a ratio for factors of production—for inputs. That's one we don't do very often. If we did I think we would put a lot more resources into the human factor. One can examine research resource allocations by levels of economic activity—by the resources that go into production, and by the resources that go into post-harvest activities. One can also examine allocation by discipline. When I hear department heads arguing about budget cuts or budget increases, I frequently find them asking, "How did soils do relative to agronomy, or to agricultural economics?"

Even though nobody really believes that the congruence model is a very useful guide to research resource allocation, it does provide useful information. If I were a research administrator, and I only had one staff person to help me in research planning, I would want him to give me the congruence ratios

by commodity, geographic area, factor of production, levels of production, and discipline. Then I would apply my intuition and ask whether the ratios make sense. When I look at the major agricultural commodities, I find that we're spending about $1.50 in research per thousand dollars of commodity value for most of the major field crops. A little bit less than that for maize, a little bit more than that for soybeans. We're spending something like $34 in research per thousand dollars for sheep and wool. The ratio doesn't need to be 1.0. But I doubt if anybody is ready to argue that the existing ratios make sense. The ratios for the minor horticultural crops, and even some of the major ones, tend to be between 8 and 15 dollars. There are some major anomalies. Some of them can be explained. But we don't rationalize across commodities very well.

Once one gets beyond the parity model, then what kind of more formal methods do we use? We're all familiar with the peer review system in which you send a project to a group of people who are supposed to know something about the project. The peer review panel scores or ranks the project. The scoring model system works best where the objective is clear. If you've already decided you're going to work on the physiology of fuelwood trees, then you can evaluate fuelwood tree projects with scoring methods. You can ask the people who have a capacity to think and know about physiology and fuel trees to evaluate and rank the projects. The ranking will give you some idea of which people can do the work and are likely to succeed.

But when one attempts to rank across the whole agricultural and/or forest area, the scoring model breaks down. I remember being involved in a scoring effort when I worked in the Phillipines. When it was all through, somebody looked back and said that what we had done was pure nonsense. After everybody put their scores down, it turned out that we had placed four times as much value on saving a peso by import substitution as we had on gaining a peso from exports. Any scoring system has an implicit set of shadow prices.

Another set of methods we see being used, particularly in agriculture, is what I would call experimental approaches. The experimental approaches have the great advantage that they can be highly decentralized. Yield-constraint studies attempt to assess the sources of yield differences between farm produce and experimental yields. An attempt is made to allocate the difference into those components that can be addressed through research, those components that have to be addressed through resource investments, those components that are affected by economic factors. Farming systems research is another way to generate this information. The advantage is that the results, usually based on interdisciplinary efforts, can feed right back into the research system—i.e., if you have a system that permits decentralized research decisions, then that knowledge can feed right back into research decisions. You don't have to convince the people involved in the research of what is important.

Within agriculture other experimental approaches have been used. For example, the selection index approach has been used to determine what a bull is worth. A relatively new area is plant growth models. It has the potential of getting down to just what constraints on plant growth are worth changing.

If we can evolve systems that are sufficiently decentralized in deciding what research can be done and what research is worth doing, then these experimental approaches are highly valuable. We need to develop systems for feeding that knowledge back up through the system without too much distortion. One of the great problems of feeding that kind of knowledge back up through the system is that at each level there is a tendency for information to degrade.

A major challenge is how to link the project selection process, or the process by which the scientific and technical judgments are brought to bear, with macro models to define sector-level research resource allocation decisions.

In any research resource allocation system, one of the things that should be kept in mind is the size of the decision one is making relative to the size of the effort that goes into the analysis for the research decision, always keeping in mind that the research is designed to make better decisions. The resources going into the research to make better decisions could also be used to do the research itself. What is the value of improving the decision?

We see some things that are rather disturbing in this area. For example, the California Legal Action Project, in its suit against the California Agricultural Experiment Station for wasting the State's money by spending it on development of tomato harvesters, is asking for a social impact statement on each research project. If that happens, we can expect some combination of (1) people lying about expected impact because the typical research project is too small to be able to carry out a thorough impact analysis, and (2) research projects getting a lot larger. That might be desirable, because I see a lot of research projects in the Minnesota Agricultural Experiment Station that are too small.

DISCUSSION II

ROBERT BUCKMAN

In forestry, Vern, I have the perception that there may be a wider set of alternatives for some agencies than there is in agriculture. In your opening remarks you said that one of the reasons for evaluation is to choose among the alternative uses of research funds. It seems to me in forestry when we have research closely linked to some fairly major action programs, that the choices could be even larger than that. Should the funds go into research or should they go into operational activities on the land itself? West Virginia Pulp and Paper Company was confronted with a problem not so long ago about whether they should purchase an additional 60,000 acres of land. They anticipated that their wood needs would increase, and the question facing them was whether they should purchase the additional land or increase productivity per acre by 10 percent. They chose to go with the 10 percent route—that is, to increase productivity 10 percent. They made a significant investment in a laboratory at Summerville, South Carolina, and felt it was more effective and cheaper to go that way. The point I'm making here is that it strikes me that the choices may be even more numerous in forestry.

VERNON RUTTAN

I agree. Any organization has to decide how much to invest in the future, in a sense, and how much to invest in the resources to expand production with existing knowledge and technology.

DAVID LEWIS

Vern, you raised an interesting issue which had to do with the allocation of resources to the evaluation process as opposed to doing the research program being evaluated. I'm curious if we have any experience that gives us either rules of thumb or some perspective on just what that allocation is?

VERNON RUTTAN

One rule of thumb is that you ought to have a good reason for departing from parity. If you knew nothing about the values of society, or about the possibility of research outcomes, you would then use the parity model. As you know more you can depart from the parity model.

CHRIS RISBRUDT

Bob, do you see the parity model being applied in forestry?

ROBERT BUCKMAN

Yes. The parity argument is normally used as I see it to favorably influence your case. We sometimes call this the index method. You always try to make invidious comparisons between somebody else's program and yours.

DENVER BURNS

That's essentially a historical trend approach which was developed in the criteria papers as being applied in RPA.

VERNON RUTTAN

It's amazing how many of these research systems one can go into and the director or associate director can't really give you those numbers. Really, all it takes is one person to spend a little time on it and you can have those values, either relative to sales or to value added.

CHRIS RISBRUDT

That's one of the problems we have in forestry. We can value so little of our research or so few of the many outputs of forestry. We have trouble with values.

VERNON RUTTAN

Again, it's a question of how precise you want to get. Even in agriculture, we haven't had published value added by commodities until fairly recently. You can approach that if you have some budget studies, or cost of production studies, if you know something about the inputs, about the production, and about the post harvest areas, and approximate value added, in the production area. Even doing it on a sales basis, or in forestry on a stumpage basis, these are the kinds of numbers I would want to know.

ALLEN LUNDGREN

It seems to me this parity model is some kind of formula funding for research. Isn't the McIntire-Stennis program a formula funding for research

based upon the extent of land area and other factors? Isn't that another kind of parity?

VERNON RUTTAN

I use the term parity deliberately here because most people think parity is a bad idea. So when I say you are using the parity model, it makes you stop and think a bit. I'm sure you've all been at meetings where somebody gets up to the blackboard and says, let's put the objectives on the board for each of these programs, and put up a big matrix, and let everybody rank them and see where we go. I think that can be useful as long as the objectives are narrow enough. But if you ask your research assistant to go out and calculate the implicit shadow prices of those rankings, you are likely to get some funny answers.

I think it is a device that people use for arguing a case. It avoids a lot of sophistication. There's something intuitive about it. So when Wisconsin—I think it was the Associate Director of the Experiment Station—comes out with this bulletin that says in essence, "The USDA is not spending enough in the Midwest. We account for 66 percent of the farm output of the country and are only spending 40 percent of the research dollars," it implies that something's wrong.

DAVID LEWIS

I think that's the question. Is it wrong? The real problem is the parity system. For organizations that supposedly thrive on change and are devoted to change, to base their allocation resources on history, strikes me as being ridiculous.

VERNON RUTTAN

It does me, too. The reason I want those numbers is so that I can depart from them. I want to know what the numbers are. Then I want to use them in developing the logic to show why we should change. One of the reasons we're low in agricultural research expenditures in the Midwest is that we grow crops that are grown on millions and millions of acres. Also, we grow a crop called maize, in which the private sector is a major performer of research. You spread those research dollars over many, many more acres than you do on potatoes, for example. But still I think the ratios are a little bit high.

ROBERT BUCKMAN

One of the parity numbers that gives me more pause than any other is that the Federal R&D dollars going to agriculture, and I think this includes forestry, now amount to about 2 percent of the total Federal R&D budget. And yet, if I add the numbers correctly, agriculture and forestry generate something approaching 25 percent of the economic activity in the country. I'm not sure about those numbers, but they provide the general idea. Agriculture, and in some respects forestry, enjoy a comparative advantage among the nations of the world. It seems to me that that kind of a parity relationship does tell us something about where the country might be investing. What's flawed about that reasoning?

VERNON RUTTAN

It's partially flawed in the sense of how it's broken down. In other words, take that 25 percent; one is counting not only the inputs of the agricultural production sector and the forest production sector, but taking the inputs used to produce them, such as farm machinery and fertilizer. So we need to add the research that's done on farm machinery. When we figure that for agriculture, we take all those wooden boxes that you forestry guys produce and we add that to get up to that 25 percent. Also, we add in the paper bags and the labor that is done in restaurants. It's important to make sure that whatever the definition is on the value side, we match that with the inputs on the research side. We shouldn't compare it just to the production research.

DAVID BENGSTON

You mentioned the University of California trial, and the concern about the social impacts of research. Do you think that we're missing the boat in forestry research evaluation, at least in the work that's been done previously, by not looking at those social impacts?

VERNON RUTTAN

I think society has a right to expect us to look at those social impacts. Any State agriculture experiment station or Federal research agency ought to have an ongoing program of technology assessment, in which the economic and social implications of potential research results are discussed with the clientele as part of public affairs extension programs. I regard the State of California as very vulnerable. I think the remedy being sought would be disastrous. The State is very vulnerable because for years they had only one man working on farm labor markets. When the mechanization process was coming along there should have been a dialogue within the State. What kind of safety nets do we need? For years, there was absolutely no protection, just as there was no Social Security for farmers until the mid-50's; there was no protection for farm workers. In that kind of situation, you

know you are going to get a political backlash. I think it makes sense to have generalized protection so you don't have to decide that a person who got a new job two weeks after he lost his job as a tomato picker is not going to be compensated, whereas somebody else who couldn't get a job for two years is going to be. If you have specific protection systems they're going to really tie you up, whether it is a tomato harvester or a Toyota that puts you out of work. But if you have a generalized protection system, then some of the political backlash can be avoided. My feeling is if we can make sure the public affairs extension program is taking these issues to the State, then we're going to have a better environment for making those decisions.

RICHARD SKOK

Based on your experience with agriculture, do you have any observation on the degree of applicability and receptiveness of research evaluation and analysis at either the State or Federal level? Is there a difference in these two?

VERNON RUTTAN

The Federal system is under new Congressional pressures to rationalize the decisionmaking process. I see that coming along in the State now. For example, in the last legislative session there was a proposal to conduct a study to advise the States of how they should go about making research funding decisions and evaluating the effects of the research. That process is underway right now.

REFLECTIONS ON FORESTRY RESEARCH EVALUATION

Richard Skok,
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As a manager of a research program I am looking for solutions that don't create new problems. In the mid-70's, I served as liaison for the Association of State College and University Forestry Research Organizations (ASCUFRO) to IR-6, which is an interregional committee of the ag experiment stations dealing with research evaluation in agriculture. Bobby Eddleman chaired that committee and there were several ag researchers from each of the regions involved. It was interesting to observe the approaches they were using, the issues they were dealing with, and the enthusiasm they generated not only among themselves, but with ag experiment station directors and with some of the Congressional staff who had access to OMB people.

It was about that time that we were doing the regional and national forestry research planning conferences with which Bob Buckman was so much involved. It was also at the time I had become dean at Minnesota, and John Ohman was North Central Forest Experiment Station Director. It was decided he would be a good one to lead the Federal coordination of those conferences. Someone was needed to represent the schools and, since I was next door, it seemed a logical selection. As we made the rounds on these conferences, I drew on this experience with IR-6. John and I talked about some other possible directions we ought to be working, besides what had become sort of generic planning activities for which forestry became rather well known. The evaluation area was one we thought might be worthwhile, based on what was happening in agriculture. About that time John was transferred into Washington as an Associate Deputy Chief for Research. Out of that came the commitment from the Forest Service to put some money into evaluation research. The Cooperative State Research Service under Jack Sullivan's leadership also made a commitment to financially support a modest effort in this area. The fact that this conference is now being held and that there are many people now involved in research evaluation in forestry bears out the results of these earlier initiatives. The real need that we saw was to build up a cadre of individuals who had the skills, capabilities, and interest to work in this area. While impetus might initially come from one location, we agreed to seek to diffuse it throughout the system. People who were interested and willing to make a commitment in this area of inquiry were the key to accomplishment.

Let me suggest a couple of thoughts concerning this area. One is the question of what is meant by research evaluation. It should be taken in a broader context than simply the economic analysis of research programs. I think evaluation analysis must address the issues of research policy in forestry. At least at the national level for the Forest Service, and at the university sector, we need to deal with emerging directions and present effectiveness of our research programs. There is an interest in better understanding what our research has done, as well as what our research can do to contribute to overall social well-being.

If I bring this thinking back home as a manager of a State-level research organization the "ball game" is quite different. In the pragmatic political environment in which one works there are a variety of factors which dictate the priorities and decisions that you establish for your research programs. Now I am not suggesting that that isn't an important element at the Federal level as well, but I don't think there is, at either the executive or legislative level of State government, the analytical capability in staffing which enables one to use the same kind of effective approach at influencing resource allocation for research.

There is much to be said, and it isn't just intuition, about maintaining a constant flow of communication with those people and groups that we see as our users of research. In the State they are of critical importance to us. One of my observations would be that we haven't done a very good job to date of convincing the practitioners in forestry of the importance of science in their activities. Practitioners often do not make a linkage between what research contributes and their management of the forest resource. I think we are starting to see some gains in

this area, but we have much to accomplish if we compare ourselves to the agricultural experience. Because of my association with the Agricultural Experiment Station, I attend many meetings where the agriculture community is dominant. When you deal with agricultural groups, there is little question in the mind of commercial farm operators about that linkage. It is an assumed relationship when they walk into the meeting. A similar meeting with forest resource management people is a quite different experience. These managers are as much our "farm operators," if you want to use that overall term.

A good share of this shortfall in scientific appreciation might be attributed right back to our education system. The forestry schools often have not done enough in educating future foresters concerning the role science plays in practice. Perhaps it has not been obvious to many of us until recently. Now one can talk about tree improvement and we can talk about many of the scientific contributions that guide present practice. It no longer is just "clinical" observation through practice that we build upon.

Evaluation is an ongoing process and it is not something new, in a sense. Someone always has been making evaluations about research programs. What you are doing through the evaluation studies approach over the last 5 or 6 years is to provide a more formal structure and objective approach. This is desirable in my view and it is something done at least partially out of necessity.

I would echo what both Vern Ruttan and John Fedkiw have said today, that you have to be cognizant of evaluation for whom and for what purposes. From the view of someone in a management mode, I would say we are looking for information that can prove useful to us as decisionmakers and also to us as individuals who try to influence other decisionmakers. In that context, your research evaluation absolutely needs to have credibility. It has to be in the hands of people in the scientific community who are not on the staffs of managers but respected in their own right as researchers. This seems to have been important to the success of the agricultural research evaluation work. The kinds of people that must lead the evaluation studies are people who have a high degree of credibility in their own research community.

For us there is always a danger in commissioning these studies. After all, we may come up with the "wrong" answers. That's a fact we face. Probably a few "wrong" answers would be useful to the credibility of the whole system. The tendency is to pick out winners early on, and obviously not all research is "winning" research. One of the troubling things about research evaluation is assuming that all research has to be winning research. If it is, then it says to me that we are probably not betting on the full range of things that we ought to be when we make our research resource allocations. One of the useful things about the wood utilization evaluation study discussed today is that it looked at several scenarios and included dollars spent on research over a much broader range than just the research that turned out the particular products that proved to be beneficial. It assigned the benefits over a much broader cost basis than traditionally has been done.

The main goal of research evaluation is to improve our research performance because it should improve our ability to manage research. From a practical point of view, we hope research evaluation also will provide justification of new and past programs of research. Work done by the group assembled here today substantiates our belief that this is a fruitful area of inquiry, relevant to the needs of our time, and important to research management and policy. The beginning has been productive yet there remains much to be done.

DISCUSSION III

JOHN FEDKIW

There are many constraints in the whole system of land management planning that have never been researched, and we know generally managers are going to be conservative and safe. Every profession is like that, and they set standards higher than they ultimately need to be. One place where research can increase the supply of timber from the national forests is by identifying resource and environmental management standards that can be set at lower levels. In some cases, they may have to be at higher levels. In any event that is a critical area in the eyes of the present policymakers, all the way up to the top of the Administration, because they're anxious for more timber productivity, and have been for the last 20 years.

One problem that has been observed in the land management process is that constraints are inconsistent between regions. For example, Region 6 has a 1,000 acres, and Region 5 has 500 acres, say, for spotted owls. These constraints impact the rate of harvesting timber, a primary concern of policymakers. Research is needed to provide valid information for spotted owl management, and valid information about other constraints. This is genuine research. Unfortunately, I don't think many scientists see it that way. And that's one of the problems that troubles us. We all say one of the problems in this whole evaluation area is that technical people and evaluation and policy people make assessments of the need for specific research, but often they don't seem to be able to agree on relative priorities in allocating resources to or within forestry research.

DAVID LEWIS

You talked about the benefits to managers of research; having worked with research evaluation for about 6 years with Weyerhauser, I'd have to say that we did a very good job of doing it as managers. One thing we did accomplish was to make the scientists aware of what their science was doing to the business they supported and by the same token to give the business a better understanding of the role of technology. I am not sure that we managed any better, but the players were better informed and maybe that ought to be a very significant role for research evaluation in terms of our profession.

RICHARD SKOK

There are many levels of research evaluation. The annual evaluation of a project at an ag experiment station, or the annual evaluation of scientists at the university represent forms of ongoing research evaluation.

ROBERT BUCKMAN

How do users foresee the forestry needs? There was a series of four regional conferences and a national conference, and there were a number of policy issues addressed in those conferences. But there was also a workshop in 1976 at Airlie House, just outside of Washington, DC, that specifically addressed policy questions. One of the things identified in that workshop had to do with competitive grants, and the workshop participants thought that forestry research ought to have a competitive grants program. A couple of years later, the organic legislation of Forest Service research was rewritten. The prohibitions were inserted into it for competitive grants. At the same time the old science structure in the Department of Agriculture was modified by Title 14 of the 1977 Farm Bill, which also wrote competitive grants, and that was reaffirmed in 1981. We would have nominated competitive grants for funding a lot earlier if competitive grants over in the Agriculture Committee in Congress weren't in such trouble. But the Committee chairman was giving competitive grants a very bad time, and the deans of agriculture were not very happy with it, so we did not do anything with it.

This past year I was visiting with a Congressional staffer and he told me that he was concerned about something still floating around in the budget process called centers of excellence. I told him that one of the ways to meet the requirements for centers of excellence might be through the competitive grants route. The next thing we knew the Senate reported out $10,000,000 in the research budget for competitive grants. That whole sequence of events, that whole evaluation, was a judgmental kind of evaluation that went back to that Airlie House workshop in 1976. Sometimes these things have a fairly short incubation period.

Evaluation takes several forms. It takes the form of periodic review with an experiment station or university by the Cooperative State Research Service. It takes the form of some Delphi techniques. Ruttan commented on this judgmental kind of evaluation.

Dick Skok and I co-chaired, a number of years ago, at Grey Towers in Pennsylvania, a workshop on basic research in forestry. There were distinguished researchers from industry, universities, and the Forest Service, and we produced a paper that dealt with basic research needs in forestry. It took that paper about 2 years to reach fruition. But the committee staffs and others asked to see copies of that paper and during our budget year Congressman Yates started to go through that basic research paper. He was going through it paragraph by paragraph, and he said "Dr. Buckman, is this true?" And then he read another paragraph, and asked again, "Is this true?" Obviously there were politics floating all through that sort of thing. The next thing that happened was the Appropriation Committee added $700,000 to our budget for basic research and biotechnology. So evaluation takes a variety of forms and I concur completely with Fedkiw that we've got to keep evaluation in front of us, and that the time for more quantitative evaluation is here. But this is not the only kind of evaluation that counts. Some of the things that don't lend themselves very well to analysis are important too. Acid rain, a dominant feature in our budget right now, is a good example.

Our safety and security in the resource area depends on examining these questions. The risks of hazards will cause this, and we have to do something about it. If we don't protect ourselves against these kinds of risks, they may be upon us and we are less prepared. Congressman George Brown, who is "Mister Science" in the Congress, and was at the last joint council meeting, said that the Congress will give you hell if you don't solve today's problems. He said the Congress will give you hell if you don't deal with those problems, but they will also give you hell if you don't anticipate an unexpected problem down the road. So Brown went on to say, since you can't win you might as well do what is right. About that point he stopped giving advice. He left very much open the question about what is right.

GARY EVANS

I'd like to reflect a little bit on Ruttan's comments about the evaluation of "tremendous agricultural successes," such as hybrid corn. He tossed the question to forestry, asking "What do you have that you can capitalize on along the same vein?" We don't have that kind of 15-year story of effects of basic and applied research that could be put together to show the multi-percentage increase.

There is a supportive comment that goes along with forestry, and this goes back to what Fedkiw refers to as ex ante *evaluation. There are many research areas in forestry right now, from forest products to forest biology, where it would perhaps pay to use some of the* ex ante *evaluation techniques to look at what future effects can be and let history be the judge. It's from some of these areas that, as we go about designing not individual research projects but research areas, the evaluation techniques that Mike Schriven wrote about almost 15 years ago can be put to play. This requires designing the research program so that what he calls pre-evaluation can be conducted as the research project plan moves forward. You look at it from the standpoint of 25 years from now—how can we evaluate what we are starting to work on now?*

*Bob Callaham basically took what material he could find and did a retrospective assessment, a very unsophisticated one, but he proved his point. Forestry research has done some spectacular things. Between these two areas (*ex ante *and* ex post *evaluations) we sit in a unique situation, especially with this group here, being able to look ahead into some of these areas and say, as we design this program for forest products research or fire research or for soil biology, how can we design it so that we can look at the end result? We have the opportunity to build this into an evaluation design.*

BILL HYDE

I am often troubled by suggestions of that sort, not because there is anything at all the matter with that suggestion but because such suggestions can quickly deteriorate. They are likely to deteriorate to a state where we say we cannot do anything because we don't have data. It strikes me that as social scientists, most of us are used to searching for and using secondary data. There are some people here who conduct surveys, and perhaps that's primary data. The rest of us are used to using secondary data, and my observations are that there are usually ways we can get at the results we are looking for with second-best data. I think we have sensible results. It is not as easy as what could have been if we could have designed the data 30 years ago, and to that extent your point is absolutely correct. But we really have to be careful overstating data problems.

CHRIS RISBRUDT

Dick, you said something about evaluations being useful to decisionmakers, and I only caught one criterion, and that was credibility. Are there others that you look for in a useful evaluation that you could categorize?

RICHARD SKOK

If it doesn't have credibility, none of the others matter.

CHRIS RISBRUDT

What if it does have credibility, then what criteria are important?

RICHARD SKOK

It depends on the decisions being made and what kind of information you're working with. Basically at the program management level I don't find a great deal of information from research evaluation that's useful. At the level of formulating a budget request for Federal funding, there are useful gains in research evaluation. Criteria such as relevance, timeliness, and applicability are involved.

DAVID LEWIS

You mean that in the sense of justification, but you do not have much to tell us about how much we ought to be spending.

RICHARD SKOK

You are really working on political problems in working out the question of the level of program support.

BILL HYDE

You don't want a researcher to tell you that your level ought to be X hundreds of dollars. But a researcher could suggest that he has evaluated two or three different problematic areas and that ex ante *evaluation suggests that area one looks considerably better than area two. Then the senior administrator would have to decide how much more emphasis to put on area one. Choosing the support level is not something that you want an economist with a computer to do for you.*

RICHARD SKOK

It is very important to look at the level of decision-making that you're influencing. At the program level, the really critical decision at any point is program direction, particularly when the opportunity to hire a new faculty member occurs. Once you have the faculty member on board, there's relatively little you can do to influence his or her research program direction, because people tend to do research in the areas that they know something about. So the hire becomes a most critical decision. Now if you move up a level, and are looking at funding a research program with Federal monies, you've got options among programs as to where you put your dollars unless you are talking about formula-funded programs. Research evaluation can tell you about where the priorities for competitive awards ought to be. Then the system will allocate the dollars, theoretically, at the place and with the people most capable of doing the research as judged by peers using scientific criteria.

DENVER BURNS

It often strikes me that the difference between what the Administration proposes as a budget and what Congress appropriates deals with areas where we don't have quantitative information. We talked about utilization, and it is an attractive area because there are a fair number of things that you can get your hands on. But a major area, at least in the Northeast, that the Congress has been interested in in a different way than the Administration, is the environmental protection and environmental information that allows current management practices to go on. Among the areas where there are substitutes, something perceived to be environmentally more acceptable will replace the predecessor. An example, is the use of BT, a biological control for gypsy moth, in lieu of chemical insecticides. The chemicals do a great job, but the people in the Northeast don't want to see them used. There are no savings in using BT, in terms of dollars and cents, but in terms of public demand and desire, there is an extraordinary difference. I don't know how we capture that as a significant component in deciding the direction that research takes in terms of absolute dollars. Tradeoffs in values are totally separate from dollars.

JOHN FEDKIW

It's an income distribution question. Some people value some things more than others, and when new research becomes available, that changes the information base, and people's perceptions change.

ALLEN LUNDGREN

This is an interesting area. We sometimes forget, especially the economic analysts, that there is more than one value system out there. Different groups of people have different value systems and judge things differently. To some, economic analysis of research has no meaning whatsoever, and they would judge research, as you say, on their perception of whether this is good or bad for the environment. I think that in any research evaluation, we have to recognize the fact that we are dealing with different bodies of constituents who may react quite differently. You have to take a broader look at research evaluation and try to address some of these issues that may end up being critical in terms of acceptability of a program. You

can take a much broader look than just looking at it from an economic standpoint.

JOHN FEDKIW

When we use market data for evaluation, we are using the opinion of many, many people. Those market prices are established by transactions agreed upon by those suppliers and users. Those market values represent real values, widely agreed upon, otherwise they would not be market values. We don't seem to have that understanding, and somehow think that an economic analysis comes out of a set of principles. No, we are measuring the value as agreed upon by many people in many transactions. Where we have market values they ought not to be put down. As a matter of fact, they maybe ought to have more weight than the opinion of half a dozen people. And that is one of the things that is not understood because economists have been trained first in principles, rather than factual observations with which biologists and physicists work.

ROBERT BUCKMAN

I will argue that the invisible hand is operating in the allocation of research as well.

JOHN FEDKIW

I don't say that the other values and biases don't have a place, because that is what the market is about. It takes facts, lies, distortion, opinion, wishes, and wants, mixes them all together, and somebody votes. And they don't tell you why. The market place also accepts facts. It's just a question of how they are weighed by the people who vote. And that is what the market is about.

DENVER BURNS

This market economy you talk about draws on available products and available supplies and demand. It's not clear to me how, within the research sector where new information is being created, that can be factored into a free market.

JOHN FEDKIW

It works through the Patent Office and patent law protects you against the free market loss. We lose some research because we don't want it to be protected that way. We want it available to all the people. We have an ambiguous kind of society in a way; we do some things one way and we do some things the opposite way. We encourage private enterprise in research by granting patents. We have even encouraged the private sector with legislation that protects them in the adoption of technology that is publicly available to everybody so the adopters will not be out-produced by other people once they get it into the market. Adoptors of unrestricted patents can lose the advantage of earning profits without some protection.

DENVER BURNS

The point I was trying to bring out, using BT as an example, was that somebody took a real risk way back, and decided to research this area even though we had DDT and chlordane and other insecticides that effectively control the gypsy moth. Somebody still thought we really ought to put some dollars into BT, despite the fact that we already had some good controls.

My interest in bringing up this subject is to point out that the evaluation of BT would show that it doesn't save any dollars at this point, at least, in terms of some of the alternatives that might be used. Yet there is something dramatic going on. The public is saying, despite the fact that there is little cost-benefit, we prefer BT. In fact, this past year there has been a cost increase in BT.

JOHN FEDKIW

So that is part of an evaluation. You give the factual data and say, well we don't gain anything with this, any net, visible, social, measurable gains. It is a perceived value although it may not be real.

CHRIS RISBRUDT

Denver's point is that for research evaluation you are in a very difficult area for values. And a significant portion of forestry research may lie in that kind of area, difficult to value.

HANS GREGERSEN

They are not in an impossible area, except from the standpoint of the traditional view of the economist looking at economic efficiency. It is just another one of the nonmeasured benefits you have to sort out, such as a perception of avoiding health problems.

Outdoor recreation is another area. Foresters have spent a lot of time just sorting out some of the numbers, whether what you come out with is some kind of cost-benefit analysis or not. I think that kind of evaluation is useful.

RICHARD SKOK

How does that evaluation problem differ from the one that we are encountering as we push more and more into basic research?

HANS GREGERSEN

The more basic the research, the more you are talking about peer evaluation of the capability of the individuals in terms of the fundamental science they are dealing with. Here we are talking about something that still has an outcome in terms of people wanting this for health or other reasons. In basic research, from my point of view, we just have to rely on a peer group evaluation of the scientists.

RICHARD SKOK

How about the issue of the level of basic research?

HANS GREGERSEN

Dick, you made the point about credibility. People who are involved in the basic sciences stay outside the broader system, in a sense; these people have been going down the road looking for their pats on the back from their fellow scientists. Credibility is established in the eyes of their peers. In the applied sciences, a researcher's credibility has to be established in the eyes of the administrator and potential user of the adopted research. Similarly, credibility with regard to research evaluations has to be established in the mind of the user of the evaluation.

GARY EVANS

What is your definition of credibility?

HANS GREGERSEN

Very simple, something that is accepted by whomever is making the decision. If you think I am credible, you'll use what I do. The definition depends on the user's perception.

I think the first thing that Dick or any decisionmaker would do is try his darndest to find something wrong with that study. But if he is using it to make it a justification statement, and it comes out positive, that still doesn't mean he is going to say it's credible. He is going to try to weigh what the people who are against him will be saying about the person who did the evaluation. I remember one of the things we ran across in reviewing research evaluation methods was a statement from a Congressional oversight hearing. Question: What was most important to Congressmen as they looked at these thousands of studies that came across their desks? Answer: The number one thing was who did the study. That is the first thing they looked for. If it's a negative result, the decisionmaker is really going to look at it, because then the program must really be bad. Other than that, if the evaluation is from an interest group and it comes out positive, they just file it away. It's similar to when you hire somebody, you get reference letters. If you get a bad one you really notice, but if it is a good one, obviously the candidate has asked people who support him. The same credibility is extremely important, but I am not sure that scientific validity in the analysis necessarily is always tied up with credibility issues.

GARY EVANS

The other thing that needs serious consideration, and is extremely difficult for the scientists to agree to, is that we need more evaluations of projects that failed. That failed miserably. This gets back to part of the decisionmakers' information base. Why did they fail? What are the problems that caused this thing to blow up? We have lots of successes, but in the evaluation area, nobody wants to drag the dirty linen out. There are some valuable lessons to be learned and some information from the standpoint of program managers and administrators that needs to come out.

JOHN FEDKIW

This is one of the characteristics of ex post *evaluation of aggregates and subaggregates. It buries the failures in the wealth of success.*

ALLEN LUNDGREN

In a marginal analysis, the anatomy of a failure could teach you a lot about how you might be able to improve the chances of success, and perhaps avoid certain kinds of failures. There is no question in my mind that we should concentrate on our successes, because if you can't justify research on your successes it is highly unlikely you could justify it on your failures.

JOHN FEDKIW

ARS did some ex post *evaluations on individual projects and when they got all through with the numbers and so forth, they said, so what? There was one interesting one they did on avian leukosis, which is one of the poultry research projects. They spent a lot of money for about 20 years. All of a sudden it started to break and they got results. The research results had enormous impacts on the poultry industry in the form of a vaccine.*

But the breakthrough was that a scientist discovered they were dealing with two diseases instead of one. And when they sorted it out, they could do the research on each and get consistent results. Before, research findings apparently just didn't come out consistently. And that seemed to be the key. I don't know how useful the information is that you might get on a project-by-project focus. We have to do a little bit of that to learn how to do program evaluation, but not a great deal of it. Ex post *evaluations of many small projects is not particularly useful for decisionmaking.*

LYNN MAISH

That was a warning that if you would have done a study somewhere before the breakthrough, you might have concluded that they wasted 20 years of effort.

DENVER BURNS

I think this is a point where the interests of people who manage differ from those of the people who are involved academically. That is, I think that all of us in our experience have seen and maybe participated in failures, to acquire a sense of what those are about.

ALLEN LUNDGREN

I have seen some generalized figures on an industry level of the analysis of research and its final implementation. These generalized figures said about 10 percent of all research projects actually produce something worthwhile, and 10 percent of those may actually pass any kind of pilot-testing stage, and of the final ones that get implemented perhaps only 10 percent of those actually are booming successes in the marketplace. But it seems that we sometimes lose sight of the fact that almost all research is a gamble. There is no way to really know in advance whether or not a particular research project or program will be successful. If you look at enough of them you can talk about probabilities of success. But you can't attach a probability of success to any one of those things. Only a certain proportion of them are going to be successful.

ANNE FEGE

But it depends on how conservative or liberal you were with the definition of the research problem, and how high a risk you are willing to take when you set it up. If you are consistently conservative you are going to have few failures.

DENVER BURNS

We strengthen and support that by studiously avoiding duplication, which is a major component of the research of companies mentioned in "The Search for Excellence." It is taboo to have duplication in agricultural research. That comes from legislative agreement.

JOHN FEDKIW

Some of that should be decided by the managers, not by the scientists or evaluators. What evaluation does is produce information useful for decisionmaking. Usually the scientists are not going to make a decision. They may not have a full concerning or a good perception of what information is going to be most useful for specific decisions at some particular time or date. In the budget cycle there comes a time when information is useful and when you pass that day, you wait another year before you can make use of it. That is the kind of thing we haven't talked about here. I believe it will be important when we get to tomorrow's discussions, which concern future directions. Scientists are not really the best judges about what we should evaluate and for what purpose. It is really something that should be determined by policy people, the people who make resource allocation decisions.

HANS GREGERSEN

That depends on the level of decisionmaking. At the project level there is information needed, too. I would predict quite strongly that at a project level, researchers are the ones who are making the decision. That may be an area we have ignored—that is, evaluations useful to researchers making their decisions, as they go from research project to research project, as opposed to a program policy or level.

JOHN FEDKIW

Ex ante *evaluation is selected to be project-oriented, or to address a group of projects that have the same end. But in the first 5 years of this research evaluation project, the decision was to focus on developing methodology, and the involvement of scientists in choosing what they were going to do was very high. Probably this is the right thing to do. But as you move forward with this evaluation effort, there is enough capability and capacity involved so that we ought to be thinking, where is it going to be most useful? The information aspect, rather than the methodology aspect of evaluation, is going to be more important the next cycle, and we should weigh that a little bit more.*

HANS GREGERSEN

I think that is a very good point. I think we have all the techniques we need. What we really have a problem with is matching the technique with the kind of information that is available.

RECENT AND CURRENT RESEARCH EVALUATIONS

A REVIEW OF CURRENT FORESTRY STUDIES

Chris Risbrudt,
USDA Forest Service,
North Central Forest Experiment Station,
St. Paul, Minnesota

In this session, we want to review and comment on the studies in research evaluation that are recently completed or in progress. Also, we want to talk about how these studies that are now in progress fit into the needs and uses that the previous speakers discussed. Joining me in this review this morning are Hans Gregersen and Bill Hyde. We picked these two because they have the most graduate students in this area, so we know there is some work being done, anyway. I think we have good graduate students working on these problems, and generally they are doing some excellent work. I would like to talk about the three problem areas in Research Work Unit 4204 at the North Central Forest Experiment Station, and to briefly note some of the studies currently underway that are not under the aegis of these two gentlemen.

We have three problem areas in NC-4204, Methods for Evaluating Forestry Research, that we have recently been approved to work on for the next 5 years. The first is measures of research productivity or, more precisely, researcher productivity. Here we are reviewing one of the traditional ways of measuring scientist productivity: publication counts. We have been tabulating them for Forest Service researchers by publication-refereed journals, station papers, other outlets, non-refereed journals, books, and others. Each Station puts out an annual attainment report where, project by project, scientist years, funding by source, and publications that result are listed. At North Central for the past half dozen years we have been analyzing our attainment report to determine number of publications per scientist year and $100,000 of research investment for each project. We are hoping we can come up with more and better measures of researcher productivity, such as an input-output analysis of research. We are also evaluating other measures, such as citation counts; the latter is probably more useful in basic research than in applied, although we are looking at both.

Our project, working with the Northeastern Station, is looking at coauthorship patterns—a sort of who influences whom issue. This helps us identify the centers of productivity, excellence, or knowledge in various fields such as short-rotation forestry. We are also developing a data base of all Forest Service publications. We have attainment reports computerized for fiscal years 1980 and 1981; this listing includes over 4,000 publications. We have found, for example, that of the authors who produced more than four publications over those 2 years, 17 percent produced 47 percent of the publications. Hence, we are looking at high and low producers on that publication scale. Are there characteristics that differ among them? Did the high producers have more cooperative funding, did they have more technicians, were they part of a bigger or smaller unit? We thought it would be interesting to look at such factors. We are well aware of the limitations of indicators such as publication counts as a measure of scientist productivity. We are reminded of the two centurions who were in charge of the crucifixion. One said to the other, "I hear he was a very great teacher"; the other said, "Yes, but he didn't publish anything." So it is one way of measuring scientist productivity, but hopefully we can begin to look at others, too.

The second problem area that we are dealing with is the diffusion of research-generated knowledge, and what factors affect it. There has been a great deal of work done in this area in other fields, and the framework for this type of study is generally established, but we want to concentrate on some of the forestry innovations. It is tempting to look just at forest products utilization research to say, for example, how fast the power backup roll has moved into industry, but we also want to look at innovations in forest management, or forest insects and disease research. How fast does this new knowledge move out into the field where it is used, and what are the important factors affecting it? Research on the diffusion of research-generated knowledge will identify the link between researcher and user.

Our third problem area, and this is where we plan to spend about 80 percent of our effort, is in developing measures for research evaluation. Here I will briefly summarize some of the studies being done

around the country. I think that is the best way to explain the kinds of things we will be working on in this area. All of these are summarized in the appendix. Bruce Bare at the University of Washington is evaluating the impacts of the regional forest nutrition research projects in Oregon and Washington, and looking at its inputs and outputs and its impacts. David Lewis is just beginning a project at Oklahoma State to identify the regional impacts of new technology, as implemented by a major firm. There is a special opportunity to do this in southeastern Oklahoma, where Weyerhaeuser bought out Dirks in 1969. We have a situation where we can isolate and determine the role research played in that decision to move in and change from an extensive to an intensive management system. The company also rebuilt the mills. Jeff Stier at the University of Wisconsin is beginning a study on evaluating the impacts of genetics research in the Lake States, which is essentially evaluating the NC-99 tree improvement cooperative in the North Central Region. That cooperative has been operating since the mid-1960's. There are records of the costs and we can estimate some of the impacts of that research.

Joe Chang at the University of Kentucky is working on a value of information study. He is estimating the value of local growth and yield tables, and trying to determine the value to forest management of additional information. As a secondary study he has examined the new growth and yield model for New England red oak. Until this yield model was developed there hadn't been a local growth and yield table or model for the New England States; they were using Midwest information. Joe estimated what the better model is worth in New England and it is rather interesting. Steve Bullard of Mississippi State is starting an aggregate study of logging research, in which he hopes to compare the effects of research in the Pacific Northwest versus the South.

These and other studies now in the planning stages will begin to form a basis for forestry research evaluation, for developing the necessary methods, and for identifying and quantifying the impacts of new knowledge. Improved knowledge of the research process itself, and its role in meeting the goals of society, should result.

THE UNIVERSITY OF MINNESOTA FORESTRY RESEARCH EVALUATION PROGRAM

Hans Gregersen,
College of Forestry,
University of Minnesota,
St. Paul, Minnesota

I will very briefly describe the studies that the College of Forestry, University of Minnesota has carried out over the past 4 years, supported with funds from the Minnesota Agricultural Experiment Station, the North Central Forest Experiment Station, the Forest Products Lab, and the USDA Cooperative State Research Service. Ten people have been involved in this effort. Table 1 summarizes the program, the specific topics addressed, and the persons involved.

Allen Lundgren was instrumental in the initial discussions and the initial choice of how to approach the problem of forestry research evaluation. We looked at it very broadly and decided the obvious thing to do first was to see what had been done in the

Table 1.--University of Minnesota forestry research evaluation program1/

A. What has been done in the past and how has it been done?
   1. Survey of methods used to evaluate research: Development of a framework for analysis.
   2. Bibliography on research management and evaluation.

B. What is involved in actually applying some of the methods?
   3. Returns to research on structural particleboard.
   4. Historical review of structural particleboard research.
   5. Returns to research on containerized seedlings.
   6. Intermediate inputs and technological progress.
   7. Factors associated with productivity growth in the U.S. forest products sector: A survey of opinions.

C. What is the nature and process of diffusion of forest research results? How does technology transfer fit into the picture?
   9. Diffusion of forestry research results.
   10. Technology transfer in the U.S. Forest Service: Some observations.
   11. Income redistribution and the value of forestry research: Issues and approaches.
   12. International technology transfer and forestry research.

D. Who needs evaluations? What do they need them for? What do they need?
   13. Forestry research planning and budgeting and evaluation needs.
   14. International comparative study of research management and planning approaches of IUFRO members.
   15. Comparative study of research management and planning approaches of U.S. IUFRO members.
   16. Approaches to estimating optimum forestry research budgets.

1/ Persons from the University of Minnesota directly involved in one or more of these studies include: D. Bengston, D. Current, H. Gregersen, J. Haygreen, I. Holland, A. Hyun, M. McDill, J. Olmstead, A. Strees, R. Westgate.

past in other fields and how it had been done, not just in forestry, but in research evaluation in general.

So the first study we started on was a survey of evaluation methods used in different fields (Gregersen *et al*. 1983a). Using this review, we then developed the framework for our future studies. We started to accumulate and digest a great deal of documentation, so the second logical project was to develop a bibliography on research management and evaluation. We made it rather broad because a lot of what we were finding dealt generally with how managers go about generating and using information to make decisions. The bibliography is now available (Westgate 1984a). It represents a drawing together of all the materials we had found in this area of research evaluation, broadly defined.

As we proceeded, we started getting uneasy about just looking at approaches without knowing what the problems are in applying them. So we decided to do some actual research evaluations to see what they really are—what's involved in them and what kinds of problems one runs into. Since most of us are economists we decided to start with economic analyses, particularly applying some of the ideas developed in the agricultural research evaluation field.

The first of our empirical studies looked at the returns to research in structural particleboard. Bengston undertook this one; he came out with rates of return between 19 and 22 percent (Bengston 1984). The main problem he ran into was lack of data, and the key challenge was to adapt approaches to availability of data. At the same time, together with John Haygreen and Andrew Hyun, we started on an historical review to trace the process of research in relation to the development of structural particleboard (Haygreen *et al*. 1985). We basically looked at the documentation on this research and linked it to what has gone on in actual practice in the structural particleboard industry. The next study was an evaluation of research on containerized seedlings. We have the preliminary results, again showing the kinds of rates of return you find in agriculture. Again, one of the main problems in this study was getting some basic numbers to put into the evaluation (Westgate 1984b).

Another major analysis was included in a study of forest products research that John Haygreen, Irv Holland, and I completed with assistance from Dan Erkkila. Our idea was to take all costs associated with forest products research—broadly defined to also include forest products marketing, logging, and engineering—and to compare these costs with the benefits of seven major innovations, admittedly seven very good ones.

We tried to see if the benefits of the seven could justify the entire research cost for the whole program area. Thus, we dealt with the common criticism that research evaluators only pick "good" projects, since we included the costs of all forest products research in our comparison. Depending upon what specifics were included, the results were internal rates of return in the 18 to 30 percent range (Gregersen *et al*. 1983b).

Other papers coming out of the University of Minnesota forestry research evaluation program deal with forestry research and income redistribution, intermediate inputs and technical change in the U.S. lumber and wood products industry, and aggregate returns to lumber and wood products research. Various manuscripts have been prepared and submitted for publication.

I think that we have already learned a lot from the evaluations in terms of the problems that exist. It is clear that we can't just sit back and look at methods in isolation. We also have to concern ourselves with building up a utilizable data base in forestry.

Another question we are addressing at the University of Minnesota is the nature of the process of diffusion of forestry research results. How does technology transfer fit into the total picture of innovation, or getting new knowledge into use and applying science and technology in the forestry field? This topic is critical because of the way we define research benefits (like John Fedkiw did much earlier): You don't have benefits until research is in use, in a pragmatic sense. Therefore, it is obviously important how fast those results get into use and how widely they get used. The first study under this heading is a general review of the literature dealing with the diffusion process and how it relates to forestry (see item in this proceedings).

Another topic being addressed is international technology transfer and forestry research. This is a study we are just starting. We have done a review of the literature, but the basic idea is to see how research from other countries is used in this country and how U.S. research results are used overseas. What kinds of things can we say about these relationships and what are the implications in terms of how the Forest Service or universities should be developing formal means for increasing certain types of international technology transfer or access to technology?

Another project we are working on deals with the who, what, and why of evaluation. We felt that before we really can make much sense out of what analysts can contribute to managers and decisionmakers, we need to review past use of evaluations.

What do managers want them for and what information do they actually need from an evaluation? To a great extent, that is what this meeting is about. Obviously, in forestry the answers relate very much to decisionmaking, to justifying decisions, and to making better allocations.

A comparison of research management and planning approaches of International Union of Forestry Research Organization (IUFRO) members is being completed. It involved sending out questionnaires to IUFRO member countries and institutions, and asking for information on research planning, evaluation and management, broadly defined, with some specific questions related to use of evaluations and evaluation needs. We have had an extremely good response rate (78 percent), considering that some of these countries don't have much capacity to spend time answering questionnaires. We received 117 responses from 58 countries. A paper on the results is available (Gregersen 1984). A very interesting result is the consistency across countries with regard to how they view certain aspects of research management and planning. One explanation is that a great number of these institutions are led by persons who were educated in the United States and Europe. In other words, people will come here or go to Europe to study and take back the management process and style and the research ideas of the countries in which they study.

A similar study of the U.S. IUFRO members is also being completed. Again, an extremely high return rate was achieved (89 percent). All universities except one responded. One of the things we want to do is to go back to the responding institutions and try to develop more detailed and concrete ideas of why certain results occur and what they mean in terms of research organization, evaluation and planning.

Finally, the last study I will mention is a look at the approaches to estimating optimum forestry research budgets. Again, we are drawing heavily on what has been done in agriculture. Literature and approaches are being looked at and a model is being developed. A thorough review has been completed by Glenn Fox of the Department of Agricultural and Applied Economics here (Fox 1985).

Some of the other papers produced in our program are included in this volume (cf. papers by Bengston, Olmstead, Westgate). We feel we have learned a lot from these diverse, yet interlinked, efforts.

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A PROPOSED FORESTRY RESEARCH EVALUATION PROJECT

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Allocating research dollars is a new topic of inquiry for forest and resource economists. Such decisions are usually made by politicians, managers, and administrators. In recent years, however, tighter budgets for both public agencies and private corporations, greater scrutiny of the public planning process, and better analytical tools have led to a more organized and disciplined inquiry into research budgeting. This raises natural questions for economics, itself a discipline of resource allocation. They are difficult questions, however, because research is a sector where the pricing system works imperfectly, if at all, yet the pricing system is the basic system on which economic analysis relies. Fortunately economists from related fields, notably agriculture and industrial organization, have struggled with similar research budgeting and allocation problems and can assist us with their insights.

The profit motive has always justified internal scrutiny of *private* research budgets, and such scrutiny is more important during financially difficult times—as the years since 1978 have been for the forest products industries. The higher profile of *public* research budgeting can be traced from a variety of recent events. Critical issues in public agricultural research were the topic of a high-level workshop jointly sponsored in 1982 by the Rockefeller Foundation and the Federal Office of Science and Technology. The Renewable Resources Planning Act of 1974, as amended in 1976, and the Reagan Administration have stimulated inquiry into public forestry research expenditures in particular. The former requires a decennial assessment of forestry in the United States, together with a planning document that includes planning for forestry research. The latter, through both the Assistant Secretary of Agriculture for Natural Resources and the Environment and the Office of Management and Budget, has expressed doubt regarding the benefits originating from public forestry research expenditures—thereby encouraging more careful measurement of these benefits. In partial response, the U.S. Forest Service established a major new research work unit to explicitly inquire into this issue (Research Work Unit FS-NC-4204, Methods for Evaluating Forestry Research). Simultaneously, two sections of the International Union of Forest Research Organizations identified research evaluation as their fundamental agenda item (S6.06-01, Evaluation of Forestry Research, and S4.05-01, Evaluation of the Contribution of Forestry to Economic Development). Finally, the Society of American Foresters acknowledged the timeliness of the topic by making "Increasing Forest Productivity" the theme of its 1981 national convention. Recognizing that research is the key to increasing productivity over time, that convention included important sessions on research evaluation and research productivity.

This paper is a consequence of this background of interest. It introduces a research program currently underway at Duke University. The overall objective of this research program is to assess the economic returns and the distributive impacts of research investments in forestry. Economic returns may be monetary as well as nonmonetary. Distributive impacts include both allocation of research benefits and costs among factors of production and allocation between producers and consumers. We intend to begin our research with a review of the institutions and mechanisms active in forestry research. We approach our objective initially with an investigation into the payoffs resulting from the aggregate of all previous forestry research and then follow up with a sharper focus on certain specific forestry research projects. The specific examples, in research areas like softwood plywood production and genetically improved seedlings, should serve as illustrative cases providing understanding of previous successes and failures as well as insight useful for future research budgeting and program planning.

Our analytical methods call on the experience of agricultural economics modified to fit the requirements of available forestry data. These data are often less precise as to geographical origin and as to specific factors of production than are comparable

agricultural data. They may also have been collected for shorter time periods. This latter difference is of particular importance when one considers the large difference in length of the production periods between forestry and agricultural products, therefore the general requirement for longer sequences of forestry data in order to draw conclusions equally as valid as those from agricultural data. Our intention is to make the methodological modifications required by these data differences of a general nature such that they may serve as guides for our empirical analyses as well as for subsequent evaluators of other forestry research projects.

Forestry research expenditures originate from both the public and private sectors, but there are several reasons to expect the public sector to dominate. A large degree of risk or uncertainty discourages private investment regardless of the expected payoffs. The long time period between biological research investments and new knowledge realized in a growing stock of timber—and finally, an expanded harvest—suggests a substantial degree of uncertainty since both the production processes and the future markets are difficult to predict. The generally small size and small market shares of most firms in the forest products industries may be the key to other factors discouraging private forestry research investments. Indivisibilities in research effort suggest a large minimum scale for research operations which in turn implies high research entry costs relative to the small size of forest product firms. Furthermore, small market shares suggest that innovative firms may be unable to claim a large proportion of the gain from their innovations. Rather, the gains from innovation may spill over to so many other firms that the spillover gains to other firms may eventually be greater than the initial gain to the innovator. We might expect small market shares to be a substantial deterrent to private research investment in the timber growing, lumber, and furniture industries, although it may be less a deterrent in the more concentrated and capital-intensive pulp and paper industry. We will test these hypotheses about firm size and private forestry research activity in the future. Meanwhile, these hypothesized factors, taken together, cause us to show greater, although not exclusive, attention to publicly funded research. This attention is also consistent with the authors' own more general concern with public policy than with the internal operations of private firms.

With this foundation of intent; that is, an objective of determining returns to investments in forestry research using appropriately modified methods from experience in agricultural economics and with some special attention to the public sector; let us consider the additional background information which this introduction can provide.

The remainder of this paper divides into three parts: background, expectations, and an introduction into the structure of the research project itself. The background section introduces the general findings of others regarding the benefits of research in agriculture and other industries. The substantial magnitude of these findings suggests, by implication, further justification for our effort. A brief survey of previous analytical methods identifies the problems encountered in the literature, and thereby anticipates problems we may encounter and recommends their solutions. This background also introduces two topics related to the benefits of research investments: technical change and technology assessment. The expectations section reviews economic theories of growth and development as they pertain to American forestry. These theories and their empirical tests provide hypotheses for our study of forestry research. The hypotheses can be seen as hints as to where we might observe the most productive forestry research experience in the past or the most productive research opportunities in the future. They also cause us to inquire into the characteristics of successful forestry research. The paper closes with a brief "guide" to the anticipated analytical components of our full research project.

BACKGROUND

Technical change is the generalized product of research. That is, research is the input and technical change is an intermediate product which, together with other inputs (land, labor, and capital), fuels the economy. Its impact is measured as the change in economic output which would occur if both the quantity and quality of all other inputs were held constant. We begin this section with a few words about the technical change literature before turning, first, to the empirical findings of the returns to research literature and, then, to the accepted methods for calculating returns to research. This methodological review will be ever-so-terse since its intents are only to relay general concepts to the reader and to acquaint him/her with the most basic analytical problems. Those with greater technical interest are referred to the methodological survey by Norton and Davis (1981).

Making the best use of resources at any moment in time is important but, in the long run, it is dynamic performance that counts. For example, consider an increase from 3 to 5 percent per annum in the rate of economic growth due to technical progress. It overcomes, in just 5 years, the effect of a static output constraint causing a 10 percent reduction in potential gross national product. An increase in the rate of growth due to technical progress from 3 to 3.5 percent overcomes a 10 percent static output effect in

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20 years. Thus, we can say that factors contributing to economic *growth,* in time, explain a large share of the *static* level of aggregate output as well.

The underlying significance of technical progress or technical change is that it substitutes new knowledge for less abundant and more expensive resources: land, labor, and capital. Research is the input that produces this new knowledge, and thereby yields increased returns to land, labor, and capital by (1) decreasing their costs and increasing their outputs, (2) increasing the quality of production and introducing new production processes, and (3) decreasing producers' vulnerability to external forces like pests and the weather.

Solow's (1957) work responds to these ideas. From 1909 to 1949, the measured United States' average increase in nonfarm productivity per worker-hour was 1.5 percent per annum. Solow found that 19 percent of this 1.5 percent was due to expanding capital intensity (i.e., more machines per worker). The remaining 81 percent of annual growth in nonfarm productivity was due to (1) technical improvement in productive inputs and productive practices (technical change in its strictest sense), and (2) increased quality of the labor force.

Denison (1974) extended this work for the years 1929 to 1969. He found that 22 percent of nonfarm productivity growth per worker-hour was due to improved education of the labor force, 48 percent to advances in scientific and technical knowledge, and only 12 percent to expanding capital intensity. Solow's and Denison's conclusions are that growth in output per worker in the U.S. originated predominantly from the application of ever newer, superior production techniques by an increasingly well-trained work force. Furthermore, their conclusions are conservative to the extent that Solow and Denison could only measure process innovation and not product innovation. Product innovation refers to changes in the quality of aggregate national output. There is no satisfactory measure of output quality changes, yet they clearly occur and as a partial result of technical change and improved labor quality, both of which are at least partially the products of research. Therefore, Solow's and Denison's impressive measures of the impacts of technical change are underestimates of the impacts of research-related activities on economic growth.

Knutson and Tweeten (1979), in extending the original methodologies of Evenson (1968) and Cline (1975), made a related inquiry into the productivity of research expenditures. They, however, restricted their attention to agriculture, specifically to all U.S. agricultural production-oriented research and extension for the years 1939 to 1972. They found a 50 percent annual internal rate of return on the marginal research and extension dollar spent in the decade from 1939 to 1948. This rate of return has tapered off since 1948. Nevertheless, it remained an impressive 35 percent for the years 1969 to 1972, the final period in the Knutson-Tweeten analysis (Evenson *et al.* 1979).

These studies examined either economy-wide technical change or the impacts of aggregate research expenditures. There have also been numerous analyses of the impacts of more specific research problems, many of them agricultural research problems.[1] Griliches (1958) initiated this micro-analytic work with his investigation of the social returns to research expenditures on corn hybridization. He found an annual internal rate of return in the neighborhood of 35-40 percent for the period 1940 to 1955. Brumm and Hemphill (1976) and Ruttan (1980) surveyed the subsequent literature. A summary of Ruttan's more recent survey is reproduced as our table 1. His categorization of the literature as either "index number" or "regression analysis" refers to the analytical method used in each article. We will discuss these methods momentarily. Ruttan found 36 articles reporting returns that range from 11 percent for wheat research in Columbia to 110 percent for both cotton research in Brazil and rapeseed research in Canada. The vast majority of the articles which he surveyed reported returns exceeding 35 percent per annum regardless of the agricultural research problem or the country which served as focus for the research. The Brumm and Hemphill survey includes nine articles on nonagricultural research problems. Rates of return reported in these nine articles are consistent with those found in the Ruttan survey.

These rates compare quite favorably with private industrial internal rates of return, which typically average 10 percent or more on capital investments and fall to the range of 2 to 5 percent at the margin. Thus, in spite of possible measurement and estimation errors and various problems inherent in comparing rates of return which may sometimes be more average than marginal, the magnitude of difference between rates of return to research, particularly agricultural research, and rates of return to general capital investments is persuasive evidence of the underallocation of resources to research. It becomes all the more persuasive when we recall that these are returns for process innovation. They overlook the currently unquantifiable benefits of research leading to new or improved products. In sum, the next

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[1]*There have also been a number of detailed case studies of particular innovations which trace out subsequent consequences. Mansfield and his colleagues (1968, 1971, 1977) provide notable examples. Griliches (1973) surveys these.*

Table 1.--Summary studies of agricultural research productivity

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (%)
Index Number				
Griliches, 1958	USA	Hybrid corn	1940-1955	35-40
Griliches, 1958	USA	Hybrid sorghum	1940-1957	20
Peterson, 1967	USA	Poultry	1915-1960	21-25
Evenson, 1969	South Africa	Sugarcane	1945-1962	40
Barletta, 1970	Mexico	Wheat	1943-1963	90
Barletta, 1970	Mexico	Maize	1943-1963	35
Ayer, 1970	Brazil	Cotton	1924-1967	77
Schmitz and Seckler, 1970	USA	Tomato harvester, with no compensation to displaced workers.	1958-1969	37-46
		Tomato harvester, with compensation of displaced workers for 50 % of earnings loss		16-28
Ayer and Schuh, 1972	Brazil	Cotton	1924-1967	77-110
Hines, 1972	Peru	Maize	1954-1967	35-40[a]
				50-55[b]
Hayami and Akino, 1977	Japan	Rice	1915-1950	26-27
Hayami and Akino, 1977	Japan	Rice	1930-1961	73-75
Hertford, Ardila, Rocha, and Trujillo, 1977	Colombia	Rice	1957-1972	60-82
		Soybeans	1960-1971	79-96
		Wheat	1953-1973	11-12
		Cotton	1953-1972	none
Pee, 1977	Malaysia	Rubber	1932-1973	24
Peterson and Fitzharris, 1977	USA	Aggregate	1937-1942	50
			1947-1952	51
			1957-1962	49
			1957-1972	35
Wennergren and Whitaker, 1977	Bolivia	Sheep	1966-1975	44
		Wheat	1966-1975	-48
Pray, 1978	Punjab (British India)	Agricultural research and extension	1906-1956	34-44
	Punjab (Pakistan)	Agricultural research and extension	1948-1963	23-37
Scobie and Posada, 1978	Bolivia	Rice	1957-1964	79-96
Pray, 1980	Bangladesh	Wheat and rice	1961-1977	30-35
Regression Analysis				
Tang, 1963	Japan	Aggregate	1880-1938	35
Griliches, 1964	USA	Aggregate	1949-1959	35-40
Latimer, 1964	USA	Aggregate	1949-1959	not significant
Peterson, 1967	USA	Poultry	1915-1960	21
Evenson, 1968	USA	Aggregate	1949-1959	47
Evenson, 1969	South Africa	Sugarcane	1945-1958	40
Barletta, 1970	Mexico	Crops	1943-1963	45-93
Duncan, 1972	Australia	Pasture Improvement	1948-1969	58-68
Evenson and Jha, 1973	India	Aggregate	1953-1971	40
Cline, 1975 (revised by Knutson and Tweeten, 1979)	USA	Aggregate	1939-1948	41-50[c]
		Research and extension	1949-1958	39-47[c]
			1959-1968	32-39[c]
			1969-1972	28-35[c]
Bredahl and Peterson, 1976	USA	Cash grains	1969	36[d]
		Poultry	1969	37[d]
		Dairy	1969	43[d]
		Livestock	1969	47[d]
Kahlon, Bal, Saxena, and Jha, 1977	India	Aggregate	1960-1961	63
Evenson and Flores, 1978	Asia-national	Rice	1950-1965	32-39
			1966-1975	73-78
	Asia-international	Rice	1966-1975	74-102
Flores, Evenson, and Hayami, 1978	Tropics	Rice	1966-1975	46-71
	Philippines	Rice	1966-1975	75
Nagy and Furtan, 1978	Canada	Rapeseed	1960-1975	95-110
Davis, 1979	USA	Aggregate	1949-1959	66-100
			1964-1974	37
Evenson, 1979	USA	Aggregate	1868-1926	65
	USA	Technology oriented	1927-1950	95
	USA	Science oriented	1927-1950	110
	USA	Science oriented	1948-1971	45
	Southern USA	Technology oriented	1948-1971	130
	Northern USA	Technology oriented	1948-1971	93
	Western USA	Technology oriented	1948-1971	95
	USA	Farm management research and agricultural extension	1948-1971	110

Source: Vernon W. Ruttan, Agricultural Research Policy (Minneapolis: University of Minnesota Press. 1982.) p. 242-243.

dollar spent for agricultural research will yield a much greater return than the last dollar invested for capital improvements in private industry. Apparently there is opportunity for considerable social gain from additional investment in research. Many more dollars could be spent on research before its marginal return falls to a level comparable to that of marginal investments in other sectors of the economy.

The natural question for us has to do with whether *forestry* research generates similarly high rates of return, thereby suggesting a similar underallocation of resources to forestry research and social gain to expanding forestry research budgets. This is the basic question for this research. There have only been scarce attempts to respond to it previously (Porterfield 1974, Davis 1967, Pee 1977, Thomson 1983 and work in progress by Gregersen and his associates).

First, however, we would like to raise our own initial unsophisticated doubt. This doubt causes us to inquire into how these impressive rates of return for research were determined. Are the methods of empirical calculation valid? Our doubt is founded in our casual observations of both many researchers who never produce and many who produce but whose work is never widely implemented. We are sure that all readers of this paper have observed both groups and would agree that both act as drains on research budgets. This suggests that there may be overinvestment in research and throws doubt on methods yielding empirical results to the contrary. In response to our observations of poor performance, however, we must ask whether such underachievement is unusual. Perhaps underachievement occurs among researchers, but it also occurs in other sectors of the economy as well. Perhaps underachievement acts as a drag on investment returns everywhere (in research, but also in the production, distribution, and service sectors of the economy), and rates of return in research are as high as they are only because underproductive research effort is substantially offset by other much more productive effort from other researchers and other research projects, an offset which is perhaps not nearly so substantial in other sectors of the economy. In this latter case our casual observations of underachievement in research may suggest areas of local improvement in research budgets. These observations are not sufficient, however, to suggest gross misallocations on a more aggregate level. If sound analytical and accounting methods are used in the research evaluation literature, then our doubt must be laid to rest.

METHODOLOGY

Two general methods have developed for evaluating returns to research: the consumers' and producers' surplus/benefit-cost method and the production function method. We will examine these methods briefly here. We will look first at the consumers' and producers' surplus method with reference to the standard supply and demand functions of the economist as drawn in figure 1.

Figure 1 shows value per unit on the vertical axis and units of output on the horizontal. The quantity of product which consumers demand varies inversely with product price according to the function D. The quantity which producers are willing to supply increases with their unit production costs according to the function S. Economic equilibrium occurs, that is, the market for our product clears, where the supply and demand functions intersect at a, or where the price consumers are willing to offer for the last unit of product is p_1, which is also the cost of producing that unit. A total of q_1 units of product exchange in this market.

Total production cost for q_1 units is the area under the supply function up to the market clearing output level or $0aq_1$. This cost pays for the variable inputs in the production process; raw materials, labor, and capital. All units of output sell at the same market clearing price p_1, therefore, all but the last unit attract payments greater than their production costs. The total of these surplus payments, $0ap_1$, is the return to the fixed factor of production, often managerial skill, and is known as economic rent or producers' surplus. Although consumers only pay p_1 for each unit of production which they consume, units consumed prior to the final unit are worth more to them. Total value to consumers for q_1 units is the area under the demand function and to the left of the market equilibrating output level or $0q_1ad$. Total value to consumers, net market payments of

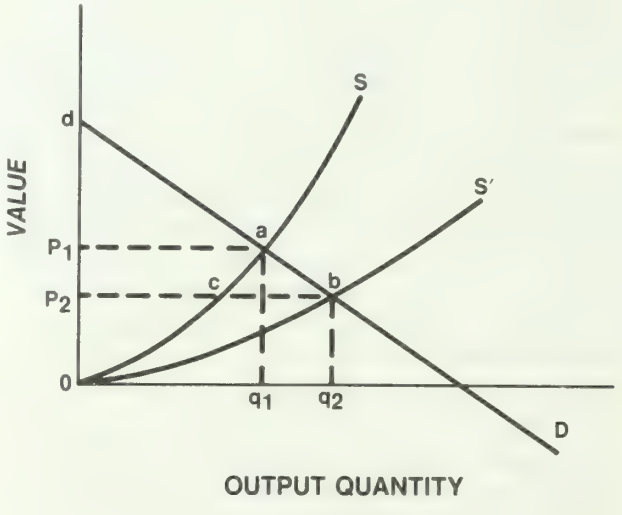


Figure 1.—*Consumer's and producer's surplus*

consumers' market, is p_1ad and is known as consumers' surplus. The gain to society from producing and consuming q_1 units of output is 0ad, or the sum or producers' plus consumers' surpluses.

The previous two paragraphs describe the static economic condition. When technical change occurs it alters much of this situation. Technical change ("process" oriented technical change to be precise) either alters the production process itself, thereby permitting use of a lower cost combination of the same inputs, or makes possible the use of a less expensive substitute input. In either case it decreases cost per unit of product such that the supply function shifts downward to, say, S' in figure 1. The new market equilibrium occurs at a lower price p_2, and a greater level of output q_2 clears the market. Technical change creates a gain in consumers' surplus equal to p_1 abp_2 and a loss in producers' surplus equal to p_1 acp_2, but a countering gain in producers' surplus equal to 0cb.[2] Technical change has no significant impact on the aggregate use of the inputs of this production process if the inputs all exchange in competitive markets and if the production process requires only a small share of the aggregate market availability of each input. In this case, factors which are released from production because of the technical change find employment in other markets and at their unchanged market prices. In conclusion, the net social gain due to technical change is $p_1abp_2 - p_1acp_2 + 0cb = 0ab$. This approach to measuring the gains associated with technical change is also known as the "index number" approach because much of the literature has concentrated on finding indices for measuring the relevant triangles in figure 1.

Benefit-cost calculations can be made for research projects using the consumers' and producers' surplus method. The annual benefits are the net social gains due to technical change (which are described above and in figure 1), while the costs are those associated with doing the research and implementing the technical change resulting from this research. One of the complexities of benefit-cost calculations is due to timing, or diffusion of the new technology over time and space. There is a large body of literature devoted to this issue, but in general we can say that research implementation costs occur in the initial year or years while benefits occur only after implementation and continue over time.[3] The common assumption is that once the new technology is fully in place, then the benefits begin—and continue unabated indefinitely. Future research and technical change only build on the basis created by past benefits. (This provides a conservative accounting of the gains to research because some technical change is necessary to maintain even a no-growth society. For example, immune treatments against pests and diseases deteriorate and must be replaced with new treatments, which are the results of new research.) Knowledge of the time streams of benefits and costs and the opportunity costs of capital permits calculation of a benefit-cost ratio for the particular research-induced technical change in question. Alternatively, in absence of a known opportunity cost of capital, many research evaluations search for the rate of return which sets the benefit stream equal to the cost stream. The result is an average rate of return for all dollars spent on the given research investment.

The second method for evaluating returns to research focuses on the production function. "Production function" is the economist's term for the physical input-output relationship described by function F in figure 2. As the physical quantity of inputs increases, then physical output must also increase, but eventually output per unit of input can increase only at a decreasing rate. Technical change makes possible an output increase using the same quantity of variable inputs as used before introduction of the new technology. It is described in figure 2 as a shift of the entire production function from F to F'. Observed output shifts would be points on these functions; for example, the initial output level q_1 using x_1 units of input may shift to output level q_2 using x_2 levels of input during a period in which technical change occurs (and quantity demand increases).

The shift in the production function must be carefully distinguished from a movement along a production function, a movement which explains the output increase due to an increase in inputs and not to technical change. In our example the output change due to a shift in the production function is $q_2 - q_2'$, while the output increase due to a movement along the function is $q_2' - q_1$. The distinction between a shift

[2] *More precisely, the benefits of research, the implementation of new technologies, spread as sigmoid functions of time and space. The common assumption referred to in the text is, therefore, conservative in that it ignores all benefits which occur before full implementation of the new technology by all who will eventually adopt it. The diffusion literature focuses on rates of adoption and identification of critical points in the sigmoid diffusion functions. See Rogers (1983), the basic text in the field, and Buongiorno and Oliviera (1977), the only forestry article familiar to us.*

[3] *We could explain this process for either the consumers' and producers' surplus or the production function approach. We will explain the original production function/residual approach only as an example.*

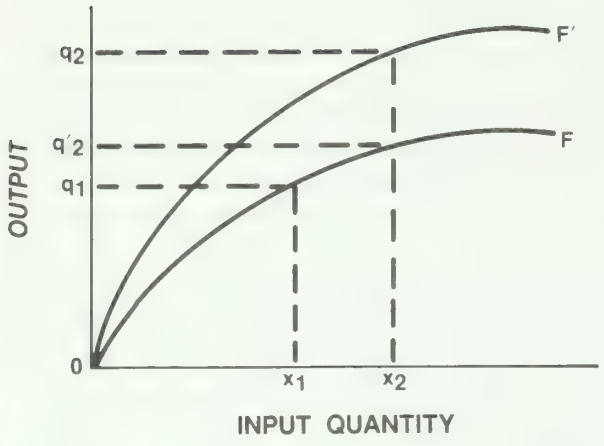


Figure 2.—*Production function.*

in the function and a movement along the function is difficult to make over time because input quality often changes, thereby contributing to and confusing measurement of any gross change in the production relationship. Accurate measures of technical change over time require inputs adjusted to reflect constant quality per unit.

The production function method for evaluating research has the advantage of permitting calculation of *marginal* research impacts. Knowledge of the functional dependence of F′ on its inputs, including its research and implementation related inputs, permits determination of the marginal physical product of any input. For example, consider the generalized form

$$F' = F'(R,K,L) \tag{1}$$

where R, K, and L are physical units of research, capital, and labor inputs, respectively. The marginal physical product of research is the first derivative of F′ with respect to changes in its physical research input—symbolically $\partial F'/\partial R$. The marginal value product of research MVP_R is simply the marginal physical product times the price of a unit of output P_Q:

$$MVP_R = P_Q[\partial F'/\partial R] \tag{2}$$

If the production function represents production in one year, then MVP_R is also measured annually. Once these benefits of research occur, however, they continue to occur year after year. Indeed, they form the basis from which future technical change occurs—and must be measured. Therefore, the marginal rate of return to research and implementation investments is that rate r which equates the discounted value of the perpetual stream of marginal research benefits with the cost of a unit of research related input p_R:

$$\int_{t=0}^{t} \tau MVP_{R(t)}(1 + r)^{-t} dt = p_R \tag{3}$$

where t = o is the year in which the research investment occurs.

One problem which arises is that capital and labor must be measured at some initial time, say t_o. Research must also be measured from some initial year, and therefore observed technical change is that which occurs between t_o and a later given year t_1. The earliest and most elementary empirical evaluations of research, whether using the consumers' and producers' surplus method or the production function method, calculate technical change as a residual. That is, they begin by estimating the functional relationship at the initial time t_o.[4] For the production function approach, this is

$$F(t_o) = F(K(t_o), L(t_o)). \tag{4}$$

The second step is to estimate the production function at a later given t_1, using the same functional form and new input levels $K(t_1)$ and $L(t_1)$, adjusted where necessary such that K and L refer to constant quality inputs:

$$F(t_1) = F(k(t_1), L(t_1)) \ . \tag{5}$$

Referring again to figure 2, this is the same as estimating the functional form F explaining the relationship between x_1 and q_1, and using this form to determine the output level q_2' which would occur with the new input level x_2. Technical change and the contribution of research inputs are assumed to be identical. They show up in neither estimate (4) nor (5), but are assumed to explain the full difference between the estimated $F(t_1)$ from equation (5) and the observed output level at time t_1. The observed level is one point (q_2, x_2) on F′ in figure 2.

METHODOLOGICAL PROBLEMS, RESOLUTIONS, AND EXTENSIONS

One difficulty that all empirical evaluations of research constantly struggle to overcome originates

[4]*Policies requiring "even-flow" of annual harvest volumes and restricting harvests to timber aged one-and-one-half times its biological maturity (itself usually twice the economic maturity) are examples. Others can be found in the expanding Wilderness System, in state forest practice acts, in high logging road standards, and in restrictions on herbicide and insecticide use.*

with inputs of varying quality. Increases in input quality can explain expanding levels even in the absence of technical change in the production process. Therefore, overlooking increases in input quality would bias upward any estimates of technical change or research impacts, yet the observed norm is for labor and processed capital inputs to do just that—to increase in quality over time as the labor force becomes better educated and as machines become more efficient. On the other hand, unprocessed capital inputs or natural resources may decrease in quality over time as society turns to lower grade and less accessible sources. Of course, decreasing quality of unprocessed capital and increasing labor quality have opposing biases on measured technical change. In sum, input quality is something to watch closely in empirical studies.

The obvious objection to the residual approach to estimating technical change outlined above is that the difference between $F'(t_1)$ and $F(t_1)$ includes both technical change and the net effect of errors in estimating the contribution of other, nonresearch-related productive inputs. Some have added that this difference also includes the impacts of scale economies in production.

Regarding scale economies, it may be true that over time the basic production operation becomes larger and that profits may result from this change in operational scale. That is, the increase in output is proportionally greater than the increase in inputs. This change in scale is not accidental, however. It must occur because of some additional knowledge about the production process—otherwise the old production operation would have been of the same larger scale. This new knowledge develops because someone carefully examined the production operation and learned a way in which the use of some basic inputs could be improved. This learning can be called research and the improved use of inputs is called technical change. Therefore, scale economies developing over time reflect technical change and shifts in production functions.

The objection that the residual between two production functions does not accurately measure technical change is valid, however. The residual calculated as we have discussed collects both a measure of technical change and the various errors attached to estimating impacts of the nonresearch inputs. The sum of these errors may be either positive or negative in sign and biases any estimate of technical change accordingly. The solution is to regress the observed difference between output levels in two periods on (a) the observed differences in constant quality labor and capital inputs, the (b) *research-related variables*, as well as on (c) any terms explaining interaction between research and other inputs. The resulting regression coefficients for the research-related independent variables then directly address the impacts of research. So long as there is no statistical collinearity between independent variables, then there is no longer any risk of collecting net estimation errors, attributing them to technical change, and identifying them as payoffs to research. The more recent economics literature makes this correction.

As empirical analyses of research impacts have become more sophisticated, they have broken the research term in their regressions ever more precisely into research itself and several related inputs. They may recognize both research and development, with development being the act of applying knowledge gained in research (Scherer 1980, p. 410). They may further divide research itself into basic and applied (Scherer 1980, p. 410) and into public and private (Cline 1975, Ruttan 1982), depending on the requirements of the particular empirical study. They may also recognize that education occurs as the handmaiden of research and hastens the pace of its implementation (Welch 1971), and that, for agriculture, extension activities play a large role in development. Finally, they may recognize that, over time, new political regulations on productions can interfere (Oster and Quigley 1977), constraining what could otherwise be sizable technical change and thereby constraining payoffs to research-related inputs. Not all of these distinctions in research-related inputs or constraints on their impacts are included as independent variables in empirical analysis, nor need they be. If they were all included, many would be statistically insignificant for any given product. It is important, however, to recognize these distinctions and to include the various research-related inputs where each is appropriate to the production process and to the objective of the particular analysis.

Questions of which research-related inputs to include in the regressions assessing technical change raise similar questions regarding cost accounting. The full cost of technical change includes the entire sequence of costs, from those associated with basic research through those associated with applied research to development costs. In application this often means public expenditure for basic research, private expenditure for modifications to satisfy specific needs, and private expenditure for development, which suggests modification or exchange of existing equipment and retraining labor.

The general experience of the U.S. Forest Service's Forest Products Laboratory provides a useful example. The Forest Products Laboratory generally undertakes risky and long-term basic research projects having to do with new product development or potential improvements in mill operations. Forest

products industrial firms generally begin to show interest when the Lab shows initial signs of research success. By then both the long time period between initial research and final application and the riskiness of research success have been reduced. Subsequently, the research components of industrial firms take the public information gained from the Lab's basic research experience and begin a race with each other and the Lab to develop the applied patents. Finally, the firms make the necessary modifications in their mills to implement the newly patented production process or to produce the newly patented product.

In other cases more common to the experience of agriculture and relevant to timber production by nonindustrial private landowners, the public sector is the source of funds for both basic and applied research. The public sector is also the source of agricultural extension funds with their educational emphasis. Of course, there may be varying Federal and State shares, with the States often becoming relatively more involved with extension. After receiving new production information from extension agents, nonindustrial private landowners then modify their newly acquired knowledge to fit their own objectives and their existing operations.

The cost of technical change is the cost of all of these research-related operations. If we choose to examine, say, Federal research expenditures, then we must recognize that we are only examining one component of the total costs of technical change. We must compare the costs of this component with only their appropriate share of total technical change, a share which can be found using proper regression techniques and two research-related independent variables, one for Federal research expenditures and the other for all other research and development. This technique avoids the temptation to count all of a given technical change as the benefit resulting from a single component of all costs, which, in this example, would unjustly ignore the efficiency of State and private research-related expenditures and inflate the efficiency of Federal expenditures. It is not unreasonable, however, to compare each independent research or development cost with its own share of the benefits of the given technical change. When doing so we must just be careful to not overlook any research and development inputs and to avoid double-counting any benefits of technical change.

We have recognized a sequence to the benefits and costs of technical change. This raises questions of the time lags between initial basic research and final implementation, and of the diffusion of successful technical change over time and space. The answers to these empirical questions vary from case to case. Nevertheless, time lags are important because only a few years' delay in implementation can substantially reduce the discounted benefits of a given technical change. We might anticipate that lags between research and implementation are shorter in concentrated industries where a few single firms have large stakes in the gains from a new technology. Therefore, we anticipate shorter lags in the relatively more concentrated pulp and paper industry than in the lumber industry, which is composed of many small sawmills (and a few larger ones). We also anticipate shorter lags in wood-utilizing industries in general than in the timber-growing industry, where much of the production occurs on small ownerships of nonindustrial forestlands. Our anticipated empirical analyses of different wood product industries will provide tests for these hypotheses.

Finally, we should introduce the related idea of technology assessment—although technology assessment *per se* is not our objective in this paper. Producing technology assessments has itself become a large activity for researchers and consultants in recent years. The Congressional Office of Technology Assessment has been particularly active, but U.S. Department of Agriculture agencies have also requested such assessments from time to time. The purpose of technology assessments is to show the impacts of a given production technology on energy, employment, environment, or whatever social, economic, and political decision criteria may be important to local communities affected by location and use of the technology in question. Because of the current popularity of technology assessments, it may be useful to comment on their relation to research evaluations like ours. The relationship is easily shown with reference to our figures 1 and 2.

Technology assessments measure the impact of a given technological change—often an anticipated change, not an actual one—shown by a shift in the supply function from S to S′ and a shift in market equilibrium from a to b in figure 1, or a shift in the production function from F to F′ in figure 2. Technology assessments require a measure of the gain displayed by these shifts, which is related to the benefits in our research evaluations. But when technology assessments ask about energy, employment, environment, or whatever, they are asking about changing use levels in the factors of production. Supply and production functions measure the impacts of the aggregate of all productive factors. Therefore, to answer these questions is conceptually simple. We need only to examine the component parts of these functions or, equivalently, the capital and labor inputs in equations (1) through (5). Of course, the empirical difficulties are that these inputs may have to be more precisely specified than

just "capital" or "labor." The specification may be particularly troublesome if (1) the distribution of a given input among affected populations is important or (2) some of the inputs are not readily measurable or, even if measurable, are treated as open access resources (as environmental inputs like air and water quality are often treated).

AN HISTORICAL PERSPECTIVE ON TECHNICAL CHANGE IN AMERICAN FORESTRY

We have commented on the disproportionate impact which others have found that research has on economic growth and we have reviewed the basic analytical methods which they used to derive their results. The methods have improved with practice. The validity of the results is established and the results themselves remain impressive. This encourages us to proceed with our specific inquiry into forestry research. Has its impact been as impressive? Before we begin with our empirical estimates, however, let us also review the history of forestry in the United States. Understanding this history may help us anticipate the locus of successful forestry research in the past, as well as some of its future characteristics.

Until the last 35 years, American forestry could be characterized by the frontier model of economic development. That is, land was relatively more plentiful than labor as a factor of timber production and transportation costs were not a substantial deterrent to harvesting. Growth in output was accounted for primarily by increased harvest area. Furthermore, the conservation model of forest development, emphasizing notions of crop husbandry and soil depletion, never fully transferred from Europe to the United States. In an economic environment characterized by high and rapidly rising wage rates, advances in mechanical technology, particularly in timber harvest and utilization, dominated the more labor-intensive conservation practices such as thinning and pruning. This describes our forest economy (only fire control may have been an exception) since the Jamestown settlement. American forestry is only now beginning to change from a frontier economy to a developed economy, where land is also a scarce factor of production.

This history is most easily seen by following the geographic expansion of forestry across the country. North America presented its European colonists with a natural endowment of mature timber. Harvest of this timber from the time of colonization through the mid-19th century concentrated in New England. The Great Lakes States' pinery was harvested in the late 19th century. There was considerable harvesting in the South throughout this time, but the South was never the dominant timber production region. In the early 20th century, timber harvesting moved to the West Coast, where the trees were big and water-borne transportation was readily available. It gradually moved down the coast from Seattle and up the coast from San Francisco. The Rocky Mountain and Intermountain West were skipped over because the timber stocking was less dense, access was more difficult, and transportation costs to the large eastern markets were great. Harvests in these regions are still not large, although they have become somewhat more important since World War II.

These geographic trends are a generalization, of course. There has always been some harvesting for local use within each region. Even within regions, however, harvest has generally followed the frontier model; from more to less accessible land, from better to poorer quality species, from better to poorer stocked timberlands, and from higher to lower grade trees.

Timber production has been characterized by *harvesting* throughout the 375 years of European development of North America. There has been little incentive to spend scarce resources *growing* timber while mature timber remains. The mature timber, however, is about gone and the period characterized by concentration on harvest technologies is drawing to a close. This event is, perhaps, hastened by public agency policy and recent environmental restrictions on timber harvesting and land use, restrictions which generally make it more difficult to harvest the remaining mature timber on public lands. In other words, the timber frontier is closing, timberland is becoming relatively scarce (more valuable), and the attention of timber producers is turning to plantation management (timber growing). Nowhere is this more important than in the South, which is becoming the leading timber-producing region in the world.

The long-term upward relative price trends of stumpage and saw logs support this view (Ruttan and Callaham 1962, Barnett and Morse 1963, Phelps 1977, Manthy 1978). These trends might be expected to continue as long as a stock of mature timber remains. Indeed, the rate of relative stumpage price increase might be expected to reflect the rate of depletion of the stock of mature timber. Berck (1978), Libecap and Johnson (1978), and Lyon (1981), in independent analyses, report empirical results consistent with this hypothesis.

Rising relative stumpage prices are entirely consistent with the expectations of the economic theory of stock resources—which is best known for its application to hardrock mineral extraction. The standing mature timber available for the early colonists was like a newly exposed mineral deposit which comprises a large share of all of that particular mineral available at some moment in time. Availability of this new deposit sharply and immediately depresses the market price of the mineral. As the new mine is gradually depleted, only deeper and lower-quality material remains. The mine's production costs increase. Eventually, the mine loses its competitive production cost advantage over other mines, and the market, including production from all other deposits of this mineral, stabilizes at some new natural price level.

Similarly, one expects stumpage prices to increase as long as there is a stock of mature timber and as harvest of this stock moves to less accessible sites, less densely stocked stands, poorer quality species, etc. The rate of price increase will eventually taper off and stumpage prices will find their natural level when all the mature timber is gone and the costs of growing timber equal the value of timber produced. The small remaining volume of mature timber in this country and the financial successes of southern timber plantation management suggest that this will occur soon. Berck (1978) and Adams and Haynes (1980) project that it will occur within the next 30 to 50 years. In other words, they expect constant relative stumpage prices within the next timber rotation.

The important questions for us are what this history suggests for technical change in the timber and wood products industries. Because technical change is the product of research, a review of harvesting history allows us to hypothesize where research has been productive and to anticipate where it may be productive in the future.

There was little incentive to develop land-saving technologies when land was relatively more plentiful than labor, and where harvests originated from a ready inventory of mature timber. Timber production per acre actually decreased in the first half of the 20th century—although aggregate output expanded during this time. (Output per acre decreased as stand density, access, species quality, etc. declined with the expanding frontier.) Incentives favored labor-saving technologies, which were *mechanical* (as opposed to biological) and which concentrated on wood utilization and processing (as opposed to timber-growing) activities. In the future, as land becomes relatively scarcer, this picture may change considerably. There may be an expanding search for ways to increase production per acre through labor-saving technical change probably of a more biological orientation.

The available evidence supports these hypotheses. The well-known advances in wood utilization and processing are numerous:

1. Introduction of steam-powered sawmills and steam-powered locomotives in harvesting (c. 1870).
2. Introduction of the band saw, reducing loss to sawdust (c. 1870).
3. Introduction of gasoline- and diesel-powered mills and woods machinery (c. 1910, exclusive use by 1930).
4. Introduction of power saws for felling and bucking (c. 1920).
5. Introduction of the sulphate pulping process, permitting the use of resinous southern pines (c. 1920).
6. Introduction of wheeled and crawler tractors for skidding (c. 1930).
7. Sawmill electrification (c. 1932).
8. Introduction of the semichemical pulping process, permitting use of hardwoods (c. 1940).
9. Development of the chip-n-saw, permitting expanded use of sawmill waste in pulping (c. 1962).
10. Development of improved lathes for plywood and veneer manufacture, contributing to the opening of the southern pine plywood industry (c. 1962).
11. Introduction of computerized scanning in sawmills, improving log utilization (c. 1970).
12. Decreasing standards in dimension lumber (2×4's are now actually $1\ 1/2 \times 3\ 1/2$ inches).
13. Increasing mill specialization, permitting decreased standards in harvested logs. (Acceptable logs in the West were 32 feet in length, they are now 16 feet. Eastern standards have decreased from 16 to 8 feet.)

While biological advances such as thinning, fertilizing, and various improvements on natural regeneration were known, they were applied only rarely and haphazardly until recently. Forest fire control may have been the exception. Certainly it has consumed major public effort since the 1930's, but the impact of this effort is difficult to demonstrate. We anticipate discussing it further in an empirical investigation of the research-fueled gains in timber production.

The few quantitative analyses support these hypotheses. Horsepower per woodsworker has increased steadily since 1919 and the capital-labor ratio has similarly increased—at a rate more rapid than that in either paper or metal products. Nevertheless, a decline in land productivity from 1910

until 1950 offset it—causing a decline in labor productivity until 1940 (Ruttan and Callaham 1962). Perhaps the decade of the 1940's marks the beginning of a change from a frontier to a developed timber economy. The value-added due to lumber processing continues to be relatively small and the rates of both productivity growth and technical progress in the lumber industry are approximately half of those for all industries for the United States in the 20th century (Kendrick 1961, Stier 1980). These rates have increased only somewhat since 1949 (Robinson 1975). Value-added by processing activities in the pulp and paper industry is much larger and the rates of both production and technical progress in this industry are more commensurate with those in other manufacturing industries. Moreover, there has been a bias toward labor-saving technical change in all wood products industries, but particularly in the sawmill and planning industry (Hunter 1955, Holland 1960, Stier 1980).

We might anticipate that these trends will continue a while longer, but without their previous strength. Forestry in general, and southern forestry in particular, is converting to more land-saving timber-growing technologies. While biological research probably has not been highly productive, it may become more so. If we find that the economic returns on biological research have been low, then we might expect to find only a small amount of private research investment. In the past, returns have been too uncertain and too distant to attract private investors. The many small timber producers may have also found investments in tissue culture and thinning regimes, for example, a severe strain on their limited financial resources. Furthermore, it is difficult to establish proprietary claims to the return on these research investments. These are all reasons why, in the past, public agencies may have been responsible for the largest share of biological forestry research. While private biological research can be expected to expand in the future, these are also reasons why public research will continue to be important.

There may be considerable transfer of new biological technologies from American agriculture, where there is more experience with biological growth functions and from European forestry, where land has traditionally been a scarcer factor in timber production. Moreover, as the leading timber-producing region, the South may expect its biological or scientific research to produce benefits which eventually spill over to all other timber-producing regions of the country. Research directed toward utilization and process technologies will continue to be attractive, as will labor-saving innovations in general. Biological research and technical change, however, may become more important components of the total forestry research effort.

ORGANIZATION OF THE PROJECT

The empirical analyses which we have begun will provide evidence for the various hypotheses raised in the historical review. We plan to set the scene for these analyses with an introduction to the institutional arrangements for funding forestry research. The main theme of the empirical analyses themselves is the effectiveness of forestry research expenditures. We attempt to calculate the economic return to dollars spent in research. We also comment on distributional impacts of research expenditures where the data and analytical method permit—focusing on distributional impacts among factors, landowner classes, geographic regions and consumers.

Our general objectives are twofold: To demonstrate the methodology as it necessarily changes for various analytical cases, and to derive policy-oriented conclusions. The convenient methodological and policy divisions are between aggregate or forestry-wide studies and industry-specific (e.g., sawmills, plywood and veneer mills, wood preserving, pulp mills, etc.) studies where analysis of research impacts are of either an *ex post* or *ex ante* nature.

	ex post	ex ante
aggregate processing	X	—
biological	X	—
industry-specific processing	X	X
biological	X	X

Ex post analyses provide critical review of previous investments in forestry research and should be conducted with the expectation of learning from previous experience. *Ex ante* analyses anticipate the benefits and costs of forthcoming research investment alternatives. They are conducted with an eye on the planning process.

Our aggregate analysis provides comment on the overall success level of previous (*ex post*) investments in forestry research. The data are such that these aggregates are best divided into four industrial subcategories corresponding to two-digit Standard Industrial Classifications (08, 24, 25, and 26, or timber growing, lumber and wood products, furniture, and pulp and paper, respectively). It is important that investigations into the first, timber growing, began early in the 20th century and include fire control research expenditures made since the 1930's. Productivity data are weak this far back, however.

Therefore, this analysis can be conducted only with some skepticism. The research contributions of the remaining three SIC code industries are more recent and easier to follow. The timber growing aggregate should shed some light on the previous general productivity of biological forestry research. The other three aggregates should provide similar insight into research leading to mechanical or timber-processing innovations.

If the aggregate analysis shows general and broad industry-wide impacts of research, then it remains for us to examine more closely the impacts of more narrowly defined and explicit research expenditures. This is the intent of three other components of our project. It is difficult to separate the impacts of explicit research projects when research may proceed simultaneously on several distinct projects within a given industry. A reasonable solution is to define the industries as narrowly as the data permit, thereby restricting the likelihood of measuring benefits to multiple research projects. Therefore, in these project components, we examine the softwood plywood industry and five four-digit SIC code industries. The presentation of our method of analysis is detailed and complete for the softwood plywood component in the hopes that this discussion may serve as a useful model for both the remainder of our project and for future work by others. There were no southern plywood mills prior to 1962, yet the South has the dominant place in the industry today. The contribution of research to southern plywood development is an important additional issue in this chapter. A second project component reviews more briefly research impacts in the five four-digit industries: sawmills, structural wood members, wood preserving, pulp mills, and paper mills. Our concentration in this component is on results, not method. The final of these three components applies the results from the previous two to ask the Schumpeterian question about research and firm size: Do firms of a larger or smaller absolute size expend greater research effort? Or does size have little to do with research expenditure while market share may be a better predictive variable? (Schumpeter 1950, chapter 2; Scherer 1980, chapter 15). Our observations from this investigation may be suggestive of which forest product industries are most likely to conduct their own (private) research and which may benefit most from greater public support and encouragement.

These are all *ex post* analyses. They can tell us what has been and perhaps throw light on the characteristics of previous research successes and failures. Another major unit of our project examines loblolly pine research, including the most important genetics research in forestry. This unit is new in its explicit biological research focus. Some loblolly pine research is really quite old, but many impacts of the research are not known with certainty. Most biological research impacts can only be anticipated today, since they are, at best, represented by standing plantations which have yet to mature and be harvested. Therefore, this unit of our project must anticipate *future* benefits to current and past research. The results of this analysis may shed light on our previous hypothesis that biological research investments in forestry will become more important as the forest economy matures in the latter part of the 20th century.

There is no need for an aggregate and *ex ante* analysis because aggregate planning decisions are generally based on either past reputation—as tested here in the aggregate and *ex post* case—or the sum of expected good decisions on specific current and future research projects. The *ex ante* analysis of loblolly pine research investments is an example of the latter.

Finally, we intend to summarize our findings and draw conclusions. They should have policy implications to research planning and expenditure in both public and private forestry. In particular, these findings should call on our general insights from the previous empirical analysis to suggest the characteristics of successful research projects, their impacts on local economies, and the justifications for both public and private research activities.

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DISCUSSION IV

DAVID LEWIS

To what degree do you see that the evaluation of any specific technology is highly conditional and the results are really dependent upon a whole range of technologies? I am not really sure that we can separate technologies, and in order for technology to have an impact, whatever it is, it has really got to be part of a whole sequence of accumulated knowledge. You can't have genetic improvement without some pretty fair nursery practices and also some stand management practices to capitalize on the improvements. What have you found?

HANS GREGERSEN

I don't think there is any question that everyone has that problem with evaluation. You have that problem with almost any kind of evaluation whether you are looking at research or anything else. This is the problem of accounting for all the costs. Obviously it depends on the particular thing you're looking at. The more detailed you try to get, the more you run into that problem. One way to get around that is to look at whole program areas.

BILL HYDE

I certainly agree with what Hans said about the more detail you get into, the more you have that problem, but it's for that reason you look at broader categories. That, incidentally, follows the idea of externalities in environmental economics. The broader you define the geographical area the better you can incorporate your externalities, therefore the fewer the problems you overlook. A second point has to do with the whole idea of questioning what has been the overlap, what has been gained from other industries. There are some ways of getting at least a handle on the spillover effects. In fact, some of the agricultural literature actually tries to measure spillovers. The third point is that you can regress outputs on expenditures and while significant correlations do not prove causation, they do lend confidence to your hypotheses.

HANS GREGERSEN

One of the intriguing questions they tackled in agriculture evaluation, to some extent, is the time length between technologies. For example, in crop improvement research, what do you do about the guy 10 years ago who fed into the ideas of research today? Similarly, if you look into the future, when do you cut off the benefits? I think agricultural research evaluations have typically taken a kind of pyramid approach with the benefits going up, and then down. I think it is an arbitrary thing in a sense, as to where you cut off the benefits of new technology and how you treat costs of the old.

BURT SUNDQUIST

Whenever you get into economic research you are faced with laying out good research, whether it be evaluation research or some other. It's dependent upon being able to "partialize" a meaningful set of events or situations. By that I mean, in the real world, at one extreme everything is related to everything else in some degree, and at the other end of the spectrum you have individual events. Evaluation at either one of these extremes typically is not very useful. So then the question is where in this spectrum can one meaningfully partialize in order to do research that corresponds to decision points, or in this case, allocation of research money, or what have you. In the final analysis, one has to be pretty pragmatic, and say it is meaningful to try to generalize from this part of the spectrum—cutting it off here—even though you realize that it's not an entirely isolated situation. One of the criteria for doing that should be, "If I can partialize at this level, does this correspond with a meaningful decision point? Does this evaluation of the subaggregate, or this situation, have some meaning in terms of somebody being able to make decisions or change their behavior on the basis of this information?"

JOHN FEDKIW

As for concentrating on who needs evaluation, largely for the budgeting and allocation question, I think that the implications of research and evaluation, both ex post *and* ex ante, *have far broader applications than that. As we accumulate this understanding of what research does to forest productivity, both in terms of total productivity and the input productivity itself, our analyses will reveal strategies which may tell us where future forest production may go in a technological sense. An outstanding example of research of that sort is sycamore silage, which was a revolutionary idea. And of course all the chipping and the fiber approaches break down the dimensional limitations of trees. This has tremendous strategic significance for research planning and forest management. Also important is raising the sensitivity of managers to what technology can do to address both problems and opportunities in resource management.*

Sensitivity to the potential of technology can do a great deal to accelerate the rate of adoption of research. Finally, there is the strategic value evaluative information to States like Minnesota and Michigan, which are looking for more job opportunities. We know from history that this type of information gives support and justification for taking initiatives, as they are doing. Industry itself is very aggressive toward the potential of new technology because it is seeking opportunity. I think we ought to take a broader look at the value of information from ex post *and* ex ante *evaluations beyond the budgeting of Federal and State programs.*

BILL HYDE

In any two industries you choose, regardless of whether they are subcomponents of forestry or of agriculture, there would be some important differences. For example, agricultural cases differ from the softwood plywood case in that the extension is important for disseminating new agricultural research results. There can be long time lags between research and implementation in agriculture. The diffusion rate and the cost of getting new information out to many farmers can be critical. In softwood plywood, however, the industry has somebody at the Forest Products Lab looking over the shoulder of the engineer who is doing the work, and there is no time lag, and no diffusion problem at all.

HANS GREGERSEN

The top eight forest products companies together have something like 80 percent of the expenditures in private forest products research. Most of the southern plywood research is private money, so it is a fairly concentrated area.

JOHN FEDKIW

For aggregate evaluation it may be easier to go at it by segments rather than comprehensively, for example: focus on what research may have done to reduce the cost of reforestation. Technology of this sort raises rates of return. Reduction in total costs of inputs in terms of unit cost per cubic foot of final product harvested or something of that sort is another important segment of the aggregate impacts of research.

It's important because the biggest cost in timber production is the cost of carrying capital. Anything that raises the rate of return because of reducing initial costs will influence the incentive that people may have to invest to expand supply.

ROBERT BUCKMAN

I wanted to comment on a couple of the technologies that have been discussed here, and I don't quite know how these observations fit in with research evaluation, but maybe they do. First, on the power backup roll. Now my guess is that we handle the benefits of the power backup roll by reductions in spin-out, the fact that we are able to put logs in a lathe that happen to be soft at the core. But I have the impression that the power backup roll may spawn a second generation of industries that we have not given much credit to. It may be possible for us to rotary-peel wood that we have not peeled before and to peel it a lot thicker than we ever have before. This raises the possibility of laying up those thick slices in parallel lamination and some of that work has already been done. But then it spawns still another possibility: On difficult-to-treat species we have lathe checks because of the thick slicing, and we could drive preservative right into the center of wood, something we couldn't do before. It is kind of an interesting second- and third-generation technology that may come out of something that was intended to reduce spin-out in a mill.

The second technology is one that is related to sycamore silage. Back about 15 years ago, the American Pulpwood Association came onto the notion that if we could separate bark from chips, we could make a major breakthrough in the recovery of pulpable species. And the American Pulpwood Association lobbied our Appropriations Committee and got funds for that activity. John Erickson and his colleagues set standards, in consultation with industry, for the amount of separation that we had to get in order to run both the chips into a pulp process. We achieved those standards. As I recall, some species were easier to work with than others. It was possible for us to chip whole trees and separate the bark from the chips. In the interim, pulp prices went up and the pulp and paper chemists discovered that they could run a lot more bark through their digesters than they thought. And so here was a fascinating technology that offered the opportunity to increase the per acre returns something like 50 percent.

The research was highly successful. It had a strong user identification and yet as nearly as I can tell it is not being used to date. I think there is kind of an interesting question about a major technology with enormous resource implications that is simply not being used. Now I don't know how we deal with that. If we are looking for something lying dormant or that is a failure maybe here is a case in point. I wonder if it's one of those technologies that is just going to lie dormant for a little while, and all of a sudden we will design a new mill to use it.

DAVID LEWIS

We looked at it very closely and it is a very interesting thing because it is quite dynamic and very much driven by the price system. At an integrated facility you've got some marginal material that can easily be identified as dirty chips. Whether it goes into fuel or into a fiber product depends in part on the price of fuel and in part on the price of composite panels. Building a facility that has the capacity to take advantage of both possibilities is the way we did it.

JOHN FEDKIW

That opens up a related question in another area of economics. What is the economics of industrial innovation; not only in general but within an industry, between industries, and between sizes of firms? We had some very fascinating demonstrations of how that works. When stumpage supplies became limited in the Douglas-fir subregion in the 1950's and 1960's, plywood capacity expanded while timber production declined. The new technology of plywood for housing applications and related prices of each products and profits, made it possible for plywood producers to outbid lumber mills for the available stumpage as little innovation occurred. Timber supplies in the West continued to dry up and become scarcer and higher priced, and we had a great deal of acceleration of improvement in mill technology. Some of it came about because of research and technology transfer on sawing methods. If we hadn't had the scarcity of supply developing in the West, mill improvements wouldn't have come nearly as fast as they did. In the housing industry, because of a high rise in lumber cost and interest rates there have been efforts to find ways to cut back costs of new homes. Truss-frame construction reduces wood required by 30 percent and provides the space enclosure that one wants in housing. The adoption of truss-frame construction is increasing steadily. There are periods when some industries are very aggressive toward new technology, and other times when profits are great and they are not interested. They aren't going to replace their old capital with new, more expensive capital as long as they're operating profitably.

AN OVERVIEW OF THE REGIONAL FOREST NUTRITION RESEARCH PROJECT

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The Regional Forest Nutrition Research Project (RFNRP) is an industry-agency-university research cooperative established in 1969 at the University of Washington. The principal objective of the cooperative is to provide forest resource managers with accurate data on effects of fertilizing and thinning young Douglas-fir and western hemlock stands in the Pacific Northwest. To achieve its objective, the cooperative has established an extensive network of permanent growth plots. These plots were located according to an experimental design which permitted regional as well as subregional analyses to be conducted. Results have been widely distributed and the project, now in its 15th year, is being extended for another 5 years.

In October, 1982, the U.S. Forest Service funded a 2-year project at the University of Washington. The objectives were to describe the inputs, outputs, application of results, and the impacts of the RFNRP on society. This case history collates all available information relative to the cooperative including: (a) the history of the RFNRP from its inception to the present; (b) the importance of strong leadership in founding and guiding the cooperative over time; (c) the total dollar investment; (d) the allocation of the total investment to salaries, supplies, travel, etc.; (e) the number of staff and graduate students supported; (f) the number of plots established; (g) publications produced by the project; (h) the principal research findings of the cooperative and their societal impacts; and (i) a benefit cost analysis of the cooperative. The purpose of this paper is to briefly review the findings of our investigation to this point. Full details of the case history may be found in a separate report (Bare and Loveless 1985).

HISTORY OF THE RFNRP

The origins of the RFNRP can be traced to discussions held during the 1960's by the Pacific Northwest Forest Soils Council. The Council, active since 1947, provided a convenient vehicle for information exchange between forest industry, university, and public agency scientists and land managers. One of the problems discussed by the Council concerned the apparent nitrogen deficiency of Northwest forest soils and its subsequent effects on site productivity. This problem was brought to the attention of the forestry community by the pioneering work of Dr. Stanley Gessel of the University of Washington, who had completed nearly 20 years of research into this problem by the mid-1960's.

In 1967, a Tree Nutrition Committee was formed by the Council to consider ways to coordinate further research into the soil nutrition problem. Even with the significant work of Dr. Gessel, research results concerning nitrogen fertilization were fragmentary and limited in scope. Consequently, no operational fertilizations were being conducted in the 1950's and early 1960's. Further, results of research fertilization trials were often inconclusive—good response to fertilization was observed on certain sites, with little (if any) response elsewhere. Recognizing this diversity and the large geographical area requiring study, the Committee suggested that a cooperative be initiated in the Pacific Northwest.

Because of Dr. Gessel's research record in this area, and his involvement on the Council, he took an active role in the formative stages of the new cooperative. Furthermore, the cooperators recognized that an institutional home with good relations among forest industry, public agencies, and academic institutions was a prerequisite for success. Historically, the USDA Forest Service has provided homes for cooperatives with regional significance. However, in this instance, the decision was made to house the cooperative at a university where institutional stability could be expected over an extended period. Consequently, the Committee, working with potential cooperators, decided to house the cooperative at the University of Washington.

Research proposals were circulated by the Committee in July 1968 and the cooperative was ini-

tiated in 1969. It's main objective was to develop information on response to nitrogen fertilizer of Douglas-fir and western hemlock over a wide range of young stands so that sound decisions could be made regarding forest fertilization. Although the original intent was to simultaneously examine the consequences of both fertilization and thinning, first-year funds were only sufficient to initiate fertilization trials.

Starting in 1969, a set of permanent plots was established in unmanaged, even-aged, fully stocked stands throughout the Douglas-fir region of western Washington and Oregon. Known as Phase I, this portion of the study involved the establishment of 85 Douglas-fir and 32 western hemlock installations in six Douglas-fir and three western hemlock provinces.[1] Each installation consisted of six plots (two control, two fertilized with 200 lb of nitrogen as urea per acre, and two fertilized with 400 lb of nitrogen as urea per acre). All plots were at least 1/10 acre in size. Plots established in 1969-1970 currently have 14 years of growth measurements.

In 1971, when additional funds became available, a second set of installations known as Phase II was established. These installations included six plots which had up to 40 percent of their basal area removed at time of establishment. Subsequently, two of the plots were fertilized with 200 lb of nitrogen as urea per acre and two were fertilized with 400 lb of nitrogen as urea per acre. A total of 35 Douglas-fir and 8 western hemlock installations was established in Phase II. Plots established in 1971-1972 currently have 12 years of growth measurements.

In 1975, Phase III of the RFNRP was initiated. The objectives of this portion of the study were to establish additional installations on poor sites and in young stands (10-20 years old) to strengthen the Phase I and II databases. Most of the young stands were precommercially thinned prior to fertilization. Twenty-three new installations were established in Douglas-fir and six new installations were established in western hemlock during Phase III. Further, one-half of the Douglas-fir Phase I and II plots were refertilized after the eighth growing season. Plots established under Phase III currently have 8 years of growth measurements.

In 1980, Phase IV of the RFNRP began. In addition to locating 14 new Douglas-fir and 4 western hemlock installations in young (8-15 years old), precommercially thinned plantations, an additional 12 Douglas-fir installations were located in poorly stocked stands. Last, four western hemlock installations were located to balance the Phase II design. Some of these latter installations had 60 percent of their basal area removed, while others had 40 percent removed. In Phase IV, the cooperative also: (a) refertilized half of the Phase I western hemlock plots originally fertilized 10 years earlier, (b) refertilized all of the Phase I Douglas-fir plots which had received a second fertilization 4 years earlier, and (c) refertilized half of the Phase II Douglas-fir and western hemlock plots. Phase IV of the RFNRP is to be completed by June 30, 1985, at which time Phase V will commence.

OBJECTIVES OF THE RFNRP

As previously stated, the primary goal of the RFNRP is to develop information to guide the planning of large-scale fertilizer applications to forest lands in the Pacific Northwest. More specific statements of objectives can be found in a variety of biennial reports, technical notes, and project proposals. Recently, Hazard and Peterson (1984) reviewed these goal statements and concluded that none of the earlier documents sufficiently states project objectives to permit the formal testing of hypotheses. They propose that the testable hypotheses underlying the RFNRP are: (a) whether fertilizer response differs among provinces; (b) whether fertilizer response differs between thinned and unthinned stands, and interacts with province; (c) whether fertilizer response differs between levels of fertilizer application, and interacts with level of thinning and province. They also propose development of predictive models for fertilizer response as a function of province, level of thinning, level of fertilizer application, interaction effects, and significant stand variables. After 15 years of plot establishment and remeasurement, many types of analysis have been conducted in an effort to provide answers to the questions inherent in these four objectives. In this report, only a brief summary of these findings will be presented. More detailed results can be found in Bare and Loveless (1985), and RFNRP biennial reports.

INVESTMENT IN THE RFNRP

The RFNRP has established about 2,000 permanent growth plots at a total direct cost of $2.5 million. Table 1 shows the annual spending pattern through FY 1984. Twenty-two cooperators have financed the cooperative on a continuing basis. Cooperators include representatives from: (a) chemical and fertilizer companies, (b) forest industry, (c) State forestry agencies, (d) Federal forestry organizations, and (e) Indian nations. Approximately 71 percent of

[1] *A definition of these provinces is contained in a later section of this paper entitled "Province Analysis."*

Table 1.--Summary of expenditures for all phases from project initiation to June 30, 1984.

(Nominal dollars)

Fiscal year	Salaries benefits, overhead	Travel	Supplies equipment, contractual services	Annual total	Cumulative total
69-70	$ 57,296.52	$ 17,179.92	$ 10,580.53	$ 85,056.77	$ 85,056.77
70-71	77,052.25	18,052.08	5,663.31	100,767.64	185,824.41
71-72	69,875.49	12,680.81	10,339.28	92,895.58	278,719.99
72-73	68,945.49	14,581.74	9,016.18	92,543.41	371,263.40
73-74	67,002.83	19,731.71	9,628.02	96,362.56	467,625.96
74-75	122,735.47	16,123.71	15,951.16	154,810.34	622,436.30
75-76	114,786.86	23,355.79	16,957.83	155,100.48	777,536.78
76-77	69,623.56	19,154.61	22,834.42	111,621.59	889,158.37
77-78	124,438.34	33,071.33	16,997.31	174,506.98	1,063,665.35
78-79	135,525.93	34,826.34	25,437.35	195,789.62	1,259,454.97
79-80	151,065.41	31,614.70	40,649.71	223,329.82	1,482,784.79
80-81	175,476.08	40,136.30	26,400.54	242,012.92	1,724,797.71
81-82	140,997.77	27,673.79	25,334.44	194,006.00	1,918,803.71
82-83	156,981.40	32,209.22	39,473.26	228,663.88	2,147,467.59
83-84	200,482.00	45,274.00	61,271.00	307,027.00	
Total	$1,732,331.00	$385,660.00	$336,534.00		$2,454,495.00

the total investment has been contributed by industry; 9 percent by the States of Oregon and Washington; and 20 percent by the Federal government and Indian nations.

Indirect costs of the cooperative not reflected in the $2.5 million of direct costs include: (a) the cost of fertilizer donated by chemical companies; (b) the contribution of university faculty, agency personnel and scientists, and industrial scientists who contributed their expertise in an advisory capacity; and (c) the time spent by cooperators in locating suitable sites for plot installations.

Approximately 71 percent of the direct costs have been expended on salaries, benefits, and overhead for project staff and graduate students; 16 percent on travel; and 13 percent on supplies, equipment, and contractual services. The cooperative has supported 2 to 5 graduate students (half-time), and 6 to 14 staff (3 to 5 full-time) per year. The project's field crew accounted for almost all of the travel expenditures and 60-75 percent of the salaries.

MAJOR RESEARCH RESULTS

RFNRP biennial reports contain an accurate and detailed chronology of the results achieved by the cooperative. Apart from a variety of special studies discussed below, the greater part of each biennial report has been devoted to a discussion of research results relating to the first three hypotheses proposed by Hazard and Peterson (1984). Thus, it is appropriate to begin this section of the paper with a brief description of these findings.

Unthinned Douglas-fir

The 10-year periodic annual increment (p.a.i.) responses to one fertilizer application as expressed in total gross cubic-foot volume/acre/year (CF/A/Y) are: (a) 40 ± 10 CF/A/Y for 200 lb of nitrogen per acre and (b) 50 ± 10 CF/A/Y for 400 lb of nitrogen per acre. This response is not significantly related to stand age, site index, or stocking variables. However, there is a general trend of increasing response as site index decreases.

Total gross CF volume p.a.i. response declines with time after treatment, and is no longer significant after the 10th year. This duration of response is longer in stands of low site index and is greater with the higher rate (400 lb per acre) of nitrogen application.

The 8-year p.a.i. responses for one fertilization as expressed in merchantable gross CF volume are: (a) 35 CF/A/Y for 200 lb of nitrogen per acre, and (b) 49 CF/A/Y for 400 lb of nitrogen per acre. Again, volume response is not significantly related to site index, stand age, or stocking variables.

Thinned Douglas-fir

The 8-year p.a.i. responses for one fertilizer application as expressed in total gross CF volume are: (a) 55 ± 6 CF/A/Y for 200 lb of nitrogen per acre and (b) 66 ± 6 CF/A/Y for 400 lb of nitrogen per acre. Again, there is no evidence that volume response in thinned stands interacts with stand age, site index, or stocking variables.

Total gross CF volume p.a.i. response declines 4 years after treatment, although the response is still significant 8 years after fertilization.

Thinned and Unthinned Western Hemlock

Neither the thinned nor the unthinned western hemlock installations have shown a significant response to the application of either 200 or 400 lb of nitrogen per acre. The only significant response for total gross CF volume has occurred in thinned young stands in one province.

Province Analysis

As previously stated, one of the objectives of the RFNRP is to test whether fertilizer response differs among provinces. Accordingly, six Douglas-fir and three western hemlock provinces located in western Oregon and Washington were delineated as geographical units based on soil and climatic factors. Analysis of 4-year growth data for Phase I Douglas-fir plots indicated that response was not significantly different across provinces. A similar conclusion was drawn from the Phase II province analysis for Douglas-fir. Hazard and Peterson (1984) have documented a statistical model which will be used to test the province response hypothesis using installation averages as the sample unit rather than individual plots as was previously done. Further, the testing will be conducted on the combined Phase I/III and Phase II/III 6-year response databases plus growth data from contract installations. These tests will provide conclusive evidence to help answer the province response questions for cooperators.

Economic Analysis

In addition to conducting mensurational studies, the RFNRP also has performed several economic analyses to determine the financial profitability of nitrogen fertilization in thinned and unthinned Douglas-fir stands. These analyses have generally shown that fertilization of Douglas-fir is an attractive investment when viewed from an incremental perspective. In this form of analysis, the incremental benefits of an activity are compared with the incremental costs of undertaking the activity. Such an analysis is only concerned with measuring the change in economic efficiency as it relates to a single treatment activity. No attention is given to the economic viability of the base investment—only to the incremental costs and benefits. Under a specified set of assumptions, these analyses have produced incremental rates of return in excess of 6 percent (real) on an after-tax basis.

General conclusions drawn from the incremental analysis of merchantable gross CF volume for both thinned and unthinned Douglas-fir stands are: (a) irrespective of fertilization treatment, site classes 2, 3, and 4 should be fertilized in that order; (b) site class 4 is not profitable to fertilize under several of the treatment schedules examined; (c) if only one fertilization is desired, timing nearest to final harvest will be most profitable; (d) if stands are to be held for two investment periods (16 years), then two fertilizations generally are more profitable than one; (e) older stands are more profitable to fertilize than younger stands; (f) 400 lb of nitrogen as urea per acre generally appears to be more profitable than 200 lb, but the optimal dosage level decreases with decreasing site class; and (g) thinned stands generate larger net present values after fertilization than do unthinned stands. Of course, these results only apply if the economic parameters used in the analysis remain valid for any particular user (Bare 1982).

The results of the incremental analysis generally show higher net present values for the more productive sites than for the poorer sites (see conclusion (a)). This follows from the assumption that trees growing on good sites are larger in diameter and have more value per unit volume than trees of the same age growing on less productive land. Thus, even though the volume response to fertilization is not significantly related to site quality, the volume response is more valuable if put on larger diameter trees.

The cooperative has also conducted an absolute net present value analysis of fertilization in thinned and unthinned Douglas-fir. This type of analysis differs from an incremental analysis in that all costs and benefits associated with a proposed treatment are considered in the analysis. Only in this manner can one determine if a stand should be fertilized and held for several years, or terminated immediately. Recall that using an incremental approach the investment is considered to be worthwhile if incremental returns exceed incremental costs. However, this form of analysis is appropriate only if the *base* investment is worthwhile, or if investment (disinvestment) decisions concerning the base investment are

not under control of the manager making the fertilizer decision.

With respect to fertilization, this means that stands with positive incremental net present values should not be fertilized unless: (a) the absolute net present value of the *base* investment is also positive or (b) the forest manager has no control over the timing of the final harvest cut in the stand. If a stand with a positive incremental net present value but a negative absolute net present value is fertilized, it implies a cost-minimization objective and not one of profit maximization.

Results of the absolute analysis of merchantable gross CF volume for both thinned and unthinned Douglas-fir stands clearly show that some stand types with positive incremental net present values (due to fertilization) should not be fertilized, but should be harvested today. Generally, however, if a stand is worth holding for another time period, it is more profitable to fertilize it rather than to leave it untreated. This, of course, assumes that investment funds are available and that they cannot earn higher rates of return elsewhere.

Miscellaneous Results

In addition to the major results discussed above, the cooperative has also conducted a series of special studies focusing on: (a) foliar and stem analysis, (b) effects of fertilization on wood quality, (c) effects of fertilization on specific leaf area and foliage retention, (d) effects of Mount St. Helens ash on the growth of Douglas-fir, (e) correlation of forest soil characteristics with fertilizer response, and (f) mineral cycling in natural and fertilized stands. A full bibliography of these and other RFNRP publications can be found in Bare and Loveless (1985).

The cooperative has also established contract installations on cooperator lands. Approximately 33 of these installations—mostly in southwestern Oregon—have been established to increase sampling intensity on the lands of specific cooperators. A variety of special analyses and reports have been prepared under these contracts.

The large database amassed by the RFNRP is available for use by cooperators who wish to conduct special studies.[2] This valuable source of information has provided the raw material for more than a dozen graduate theses at the University of Washington. It is expected that the value of this database will grow as additional fertilization treatment installations are added.

APPLICATION OF RFNRP FINDINGS

Benefits of the RFNRP include the adoption of the above results by land management agencies and their subsequent impacts on society. Obviously, the principal benefit of the cooperative is the quantification of the effects of nitrogen fertilizer on the growth of thinned and unthinned stands of Douglas-fir and western hemlock. These findings have been adopted by both cooperating companies and agencies as well as organizations which have not directly financed the cooperative.

A recent survey by the RFNRP reveals that 18 forest industry companies and four Federal/State agencies have fertilized nearly 1.6 million acres in western Oregon and Washington over the past 10 years (Chappell and Opalach 1984). All survey respondents indicated that a dosage of 200 lb of nitrogen as urea per acre was applied aerially. For the last half of the decade (i.e., 1979-1983) an average of 155,000 acres per year was fertilized.[3]

Although we have no way of determining how many acres were fertilized annually because of the presence of the RFNRP, it appears that the cooperative has made significant contributions in this regard. This is borne out by the continuing involvement of companies and agencies in the cooperative and their interest in RFNRP research reports detailing new results.

Some companies and agencies have fertilized young stands to increase the harvesting of old-growth reserves and to improve age class distributions. Generally, such organizations operate under some type of sustained yield timber regulation policy which dictates that long-term harvest rates do not exceed growth rates. Thus, with a fixed land base, the only way to increase harvest rates is to increase growth rates. This has led to adoption of the allowable cut effect or earned harvest factor form of analysis by several companies and governmental agencies. Many authors believe that the increased harvesting of old-growth reserves can be directly tied to the fertilization of adjacent young stands and claimed as a direct benefit of the fertilization expenditure. We do not endorse this concept of analysis. However, it is reported herein because this form of analysis has led to the fertilization of young forests

[2]*All requests for data are evaluated by RFNRP staff to determine if the request satisfies the requirements of the cooperative's data-sharing policy.*

[3]*This figure does not include fertilizations occurring on the nonindustrial private ownership land base in the Pacific Northwest.*

in the Pacific Northwest. To the extent that the cooperative contributes to the fertilization decision, it has indirectly had a societal impact.

Closely related to the issue raised above is the use of fertilization to reduce the size of the allowable cut falldown. This phenomenon occurs when a sustained yield timber regulation policy leads to a reduction in old-growth growing stocks over one rotation. Because young stands do not produce volumes per acre equal to those of old-growth stands, there is a sudden reduction in timber harvests as the second rotation begins. One way to reduce this "gap" is to increase the growth rate of the young stands through fertilization. Without passing judgment on the validity of this form of analysis, it is clear that some organizations are fertilizing their young stands with the objective of reducing the size of their allowable cut falldown. Again, to the extent that the cooperative contributes to this decision, it has had an indirect effect on society.

BENEFIT/COST ANALYSIS

One of the more important issues confronting budget analysts and managers of research programs is the benefit/cost performance of research expenditures. These questions arise when new programs are being considered as well as when past or existing programs are being evaluated. In both instances, the critical question is one of measuring the costs of a research program against the benefits expected to flow from the program.

A series of preliminary benefit/cost analyses is developed in this section of the paper. These analyses measure the benefit of fertilization as a joint product of the investment in the cooperative plus the application cost of the fertilizer. A benefit/cost analysis of investments in the cooperative itself is not presented because no reasonable means could be found for allocating project benefits to the investment in the cooperative versus the direct cost of application.

Previously, we indicated that the direct dollar investment in the RFNRP totals $2.5 million as expressed in nominal dollars. To account for inflation, each year's investment is converted into constant (1983) dollars. As shown in table 2, these annual dollar investments have remained relatively stable over the life of the project. For purposes of the benefit/cost analysis, direct dollar investments in the cooperative are continued for an additional 5 years to reflect the anticipated funding for the Phase V extension of the project.

The cost of aerially applying fertilizer averaged $53/acre in 1983 (Chappell and Opalach 1984). This cost is held constant in real terms over time in the benefit/cost analysis beginning with 1983. However, a trend line analysis of past fertilizer application costs clearly shows a decreasing cost from 1973-1983. Thus, fertilizer treatments initiated prior to 1983 are estimated using the results of the trend line analysis (table 3).

The benefit due to fertilization is assumed to be the value of the resultant increase in wood yield. For simplicity, this incremental approach is limited to one fertilization of 200 lb of nitrogen as urea per acre in an unthinned stand of Douglas-fir. The 10-year periodic annual increment as measured in total gross CF volume was earlier shown to be 40 CF/A. Since response is not significantly related to stand age, density or site productivity, the economic analysis applies to an average acre. The 400 CF/A of additional wood is harvested at the end of the 10th year following fertilization.

The stumpage value of the incremental wood yield is held constant at $.50/CF. This is equivalent to approximately $100/MBF using a BF/CF ratio of 4.5/1.0. All benefits are expressed in 1983 dollars and are held constant in real terms over time beginning in 1970. The duration of response from the application of fertilizer is assumed to be 10 years.

It is also assumed that no fertilization decisions are based on results produced by the cooperative until the beginning of the fifth year. Thus, as depicted on the work sheet shown in table 4, the first application of fertilizer does not appear until year 5. Accordingly, the first benefit of $200/acre does not occur until year 14. Similarly, the analysis assumes that a second acre is fertilized at the beginning of year 6, with benefits being realized in year 15. This sequence of application investments and lagged benefits is assumed to continue until the present value of the last benefit falls below $1/acre. Therefore, the length of the investment planning horizon is a function of the discount rate used in the analysis. As previously noted, the investment in the cooperative itself is assumed to terminate in year 20.

All benefit/cost analyses are conducted on a per-acre basis even though more than one acre is involved in the analysis. Hence, the difference in size of the investment introduced by different lengths of investment planning horizons is automatically accounted for. The investment in the cooperative is placed on a per-acre basis by expressing the investment on a per-acre fertilized basis. Because there is no way to determine the number of acres fertilized due to the cooperative's presence, four scenarios are considered. It is assumed that 100, 50, 20, and 10 percent of the 155,000 acres fertilized annually during the past 5 years can be attributed to the cooperative. Thus, per acre investments in the cooperative range from $1.54/acre (in constant 1983 dollars)

Table 2.--Adjustment of RFNRP budget from nominal to constant dollars

GNP Implicit Price Deflators					
Calendar year	1972[1]/ dollars	1983[2]/ dollars	Fiscal year basis	RFNRP budget (nominal dollars)	RFNRP budget 1983 (constant dollars)
1969	86.79	40.158			
			41.236	85,057	206,269
1970	91.45	42.314			
			43.369	100,768	232,350
1971	96.01	44.424			
			45.3415	92,896	204,854
1972	100.00	46.271			
			47.6565	92,543	194,188
1973	105.75	49.042			
			51.2055	96,363	188,189
1974	115.08	53.369			
			55.8525	154,810	277,176
1975	125.79	58.336			
			59.855	155,100	259,126
1976	132.34	61.374			
			63.1615	111,622	176,725
1977	140.05	64.949			
			67.3535	174,507	259,091
1978	150.42	69.758			
			72.7725	195,790	269,045
1979	163.42	75.787			
			79.3165	223,330	281,568
1980	178.64	82.846			
			86.7575	242,013	278,953
1981	195.51	90.669			
			93.3055	194,006	207,926
1982	206.88	95.942			
			97.971	228,664	233,400
1983	215.63	100.00			
			101.0365	307,027	303,877
1984	220.60	102.073			
Total				2,454,495	3,572,737

1/ Source: President's Economic Report, February 1983, and Survey of Current Business, June 1984.
2/ 1983 Dollars = 100.000

Table 3.--Assumed costs of aerial application of 200 lbs. of nitrogen per acre

(1983 Dollars per acre)

Year	Application cost
1974	76
1975	74
1976	71
1977	69
1978	66
1979	63
1980	61
1981	58
1982	55
1983	53
1984-2084	50

1/ Trendline analysis of data from Chappell and Opalach (1984)

Table 4.--Sample worksheet at 12 percent

Fiscal Year	End of year[1]	RFNRP invest/ac[2]	PV RFNRP invest[1]	Application invest/ac[1]	PV application costs	Benefit before tax[1]	PV before-tax benefit[2]	After-Tax Benefit[1] 28% Cap. Gain	Amort.	Total	PV After Tax[2]
70	0	1.331	1.331	0	0						
71	1	1.499	1.195	0	0						
72	2	1.322	0.941	0	0						
73	3	1.253	0.892	0	0						
74	4	1.214	0.772	76.43	48.57						
75	5	1.788		73.79	41.87				7.032	7.032	3.990
76	6	1.672		71.14					13.820	13.820	7.002
77	7	1.140		68.50					20.365	20.365	9.212
78	8	1.672		65.86					26.667	26.667	
79	9	1.736		63.21					32.726	32.726	
80	10	1.817		60.57					31.510	31.510	
81	11	1.800		57.93					30.294	30.294	
82	12	1.341		55.29					29.078	29.078	
83	13	1.506		52.64					27.863	27.863	
84	14	1.999		50.00		200.00	40.924	144.00	26.647	170.647	
85	15	1.539		50.00		200.00	36.538	144.00	25.432	169.432	
86	16	1.539		50.00		200.00	32.624	144.00	23.730	167.730	
87	17	1.539							23.243	167.243	
88	18	1.539	0.200						23.000	167.000	
89	19	1.539	0.179						23.000	167.000	
90	20		Σ =12.400								
91	21										
92	22										
	36				0.846						
	37			50.00	0.755				23.000	167.000	
	38				Σ =357.720				23.000	167.00	
	39							144.00	18.400	162.400	1.950
	40							144.00	13,800	157.800	1.700
	41								9.200	153.200	1.470
	42								4,600	148.600	1.270
	43									144.000	1.100
	44									144.000	.983
	45						1.220			144.000	.878
	46					200.00	1.089			144.000	.784
	47					200.00	.972	144.000		144.000	.70
							Σ =373.8548				Σ =374.46

1/ 1983 dollars
2/ 12 percent

under the 100 percent scenario to $15.40/acre under the 10 percent scenario.

The results of the benefit/cost analysis are summarized in table 5, where both before- and after-tax net present values are shown. The after-tax net present values are based on the assumption of a corporate taxpayer who is subject to a 46 percent tax rate on ordinary income, 28 percent tax rate on long-term capital gains and a 6.5 percent harvest excise tax. As shown in table 6, the cost of fertilizing is amortized over a 5-year period. The results clearly show that under the assumptions employed in the analysis, the incremental investment in fertilization has generated rates of return in excess of 9 percent (expressed in 1983 dollars). The exact internal rate of return earned on the joint investment in the cooperative and the cost of application are displayed in figure 1. As shown, the real after-tax (1983 dollars) internal rates of return are 9.3, 10.7, 11.7, and 12.1 percent for the 10, 20, 50, and 100 percent acreage scenarios, respectively.

The results shown in table 5 agree closely with the results of the economic analyses previously discussed in this paper. This is not too surprising when one remembers that the per acre investment in the cooperative is only about 3 percent of the per acre application cost (assuming the 100 percent acreage scenario) and that the prior economic analyses have shown large positive incremental net present values (excluding the cooperative investment). Thus, from this preliminary assessment, it appears that investments in fertilization in the Pacific Northwest (including both the investment in the cooperative and the cost of application) have produced adequate improvements in the financial posture of the organizations involved. However, our analysis does not reveal whether these organizations are: (a) minimizing losses or maximizing profits through their actions or (b) earning the maximum rate of return on their investment dollars. Answering these questions requires an absolute analysis as discussed in an earlier section of this paper.

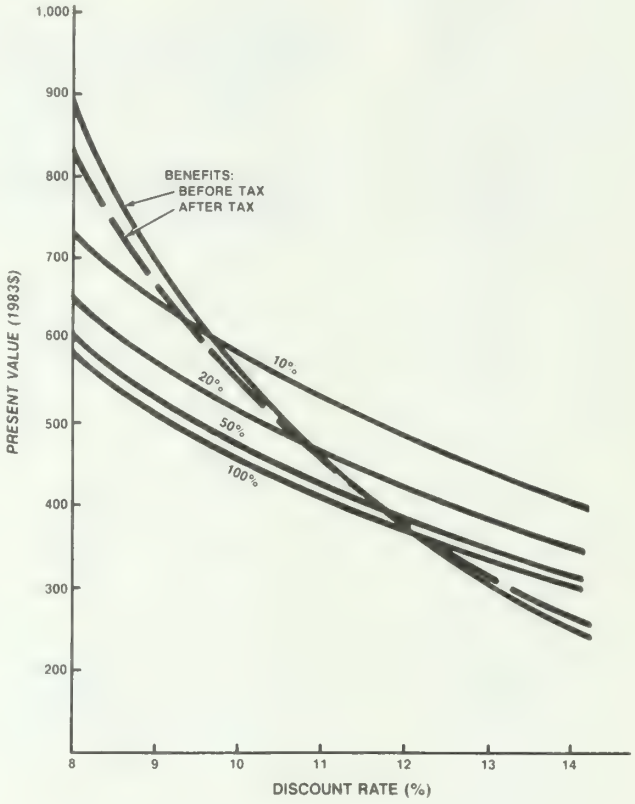


Figure 1.—*Graphical solution showing rate of return.*

Table 5.--Summary of benefit/cost analyses

Discount rate	INVESTMENTS: Cooperative	INVESTMENTS: Application costs	INVESTMENTS: Total 1/ 100%	50%	20%	10%	BENEFITS: Before taxes	BENEFITS: After taxes 2/	Years 3/ in planning horizon
-percent--	---dollars---								---years---
6	18.37	788.97	807	826	881	973	1545	1364	90
8	15.92	574.65	591	607	655	734	906	831	68
10	13.97	444.67	459	473	515	584	569	544	55
12	12.40	357.72	370	383	420	482	374	374	47
14	11.12	294.03	305	316	350	405	253	266	40

1/ The columns under total are for different assumptions concerning the amount of acreage fertilized that can be attributed to RFNRP--i.e. 20% assumes that the cost of the RFNRP is spread over 20% of the 155,000 acres fertilized.

2/ A yield tax rate of 6.5%, income tax rates of 46% for corporate ordinary income and 28% long-term capital gains were used. All fertilization expenditures were amortized over 5 years.

3/ Years in planning horizon refers to the length of the horizon used in each analysis. At 6%, the analysis was carried for 90 years, as this is the point at which the present value of the annual before-tax benefit becomes less than $1/A.

Table 6.--Benefits from decreased taxes by amortization[1/]

End of year	Calculation	Fertilization (years amortized)
5	(One-fifth of current year's fertilization cost) x .46 = (1/5) (76.43) x .46 = 15.286 x .46 = 7.632	5
6	15.286 + (1/5) (73.79) x .46 = 30.044 x .46 = 13.820	5, 6
7	30.044 + (1/5) (71.14) x .46 = 44.272 x .46 = 20.365	
8	44.272 + (1/5) (68.50) x .46 = 57.972 x .46 = 26.667	5, 6, 7, 8
9	57.972 + (1/5) (65.86) x .46 = 71.144 x .46 = 32.726	5, 6, 7, 8, 9
10	55.858 + (1/5) (63.21) x .46 = 68.500 x .46 = 31.51	6, 7, 8, 9, 10
11	53.742 + (1/5) (60.57) x .46 = 65.856 x .46 = 30.294	7, 8, 9, 10, 11
	"	"
	"	"
	"	"
	"	"
	etc.	etc.

1/ Sample Worksheet
Amortize the cost of fertilization over a 5-year period beginning the year after fertilization (straight-line, one-fifth of the cost each year, assume a 46 percent Federal ordinary income tax). 1983 dollars per acre.

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AGGREGATE RETURNS TO LUMBER AND WOOD PRODUCTS RESEARCH: AN INDEX NUMBER APPROACH[1]

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Economic evaluations of investments in research have either focused on detailed case studies of specific innovations or else attempted to assess the impact of research on productivity growth at some level of aggregation. Case studies have been useful for building up a stock of knowledge about the effects of major technological innovations and for developing research evaluation methodology. Examples include Griliches' (1958) evaluation of hybrid corn research and the evaluation of industrial innovations by Mansfield *et al*. (1977). But studies such as these are sometimes criticized for considering only highly successful research efforts, thus casting doubt on their representativeness for a given field or industry. To the extent that this criticism is valid, it is unclear what conclusions can be drawn from research evaluation case studies.

Aggregate level research evaluations avoid the "success story" criticism by ignoring individual technologies and instead examining the relationship between research and the growth of productivity in an entire industry or sector of the economy. Broad policy implications are more likely to follow from this type of evaluation. Many aggregate evaluations of production-oriented agricultural research have been carried out, including the early work of Tang (1963), Griliches (1964), and Latimer and Paarlberg (1965).

The purpose of this paper is to describe and apply a simple methodology for evaluating the social returns to research at the level of an entire industry. The index number approach was first developed by Peterson (1971), although the basic idea may be traced to the seminal research evaluation work of Schultz (1953). Briefly stated, the idea is that "research output can be evaluated indirectly by measuring the productivity of the industry toward which the research is directed," (Peterson and Fitzharris 1977). Productivity growth has been used to evaluate agricultural research in several studies. Eddleman (1977) and Lu *et al*. (1978) used projected productivity indexes to estimate future returns to agricultural research. Hastings (1981) examined the relationship between agricultural research and productivity growth, and found a positive relationship between research, climate, and aggregate productivity.

As an illustration of the index number approach, the returns to past research in the U.S. lumber and wood products industry (SIC 24) will be considered. It is found that average rates of return to this research over the period 1942 to 1973 have been quite high. The implications of these findings and several unresolved issues in research evaluation are discussed in a concluding section.

METHODOLOGY AND DATA

Perhaps the most vexing problem in evaluating research from an economic perspective is measuring the value of research outputs. The value of new knowledge—the main output of research—cannot be measured directly. Hence, research evaluators have been forced to use various proxies for research output, including numbers of publications and specific innovations produced by research.

The index number approach uses growth in productivity to indirectly measure research output as the value of resources saved due to more efficient production techniques (Peterson and Fitzharris 1977). For example, suppose that output per unit of input increased by 10 percent between 1970 and 1980 for some industry, and that the value of the industry's production in 1980 was $5 billion. If the inputs used in 1980 had been combined using 1970

[1]*Research supported by the Department of Forest Resources, the Agricultural Experiment Station, University of Minnesota, and the USDA Cooperative State Research Service. The author thanks Professor Hans Gregersen and Professor Willis Peterson for helpful comments and suggestions during the course of this research.*

production technology, $500 million (5 billion times 0.10) less output would have been produced. This $500 million therefore represents the savings in the industry in 1980 due to technical change.

Measuring aggregate research benefits in this way is completely analogous to the approach used in most economic evaluations of research: Technological advances resulting from research cause an upward shift in a production function, which is equivalent to a rise in an index of total factor productivity. Consumer surplus research evaluations use essentially the same approach, except that information about elasticities of supply and demand and the type of supply shift induced by research are included. The beauty of the index number approach lies in its simplicity and directness.

The index of total factor productivity or technical change used to calculate research benefits was derived by Bengston and Strees (1984). This index corrects a bias in a previously reported index of technical change (Robinson 1975) by explicitly including intermediate inputs.[2] It measures increased output of lumber and wood products not accounted for by increases in capital, labor, and intermediate inputs. As shown in figure 1 and table 1, the index was set equal to 1.0 in 1951 and had risen to about 1.4 by the early 1970's. This indicates that due to technical change, it became possible over this period to obtain about 40 percent more output from the same bundle of inputs.

A 3-year moving average was taken to smooth out unusual fluctuations in the productivity index. Wide variations from year to year in an index such as this are likely due to difficulties in measuring the capital input. The swings do not indicate annual changes in productivity. The smoothed index therefore better represents overall trends in productivity growth.

Annual research benefits were calculated by multiplying the increase over the base year of the smoothed index by the annual value of production in the lumber and wood products industry:

$$R_t = [A'_t - 1]\, Q_t \ ,$$

where R_t is gross research benefits in year t, A'_t is the smoothed index of total factor productivity, and Q_t is the value of production in year t (in constant dollars). Research benefits calculated for the years covered by the productivity index are given in table 1.

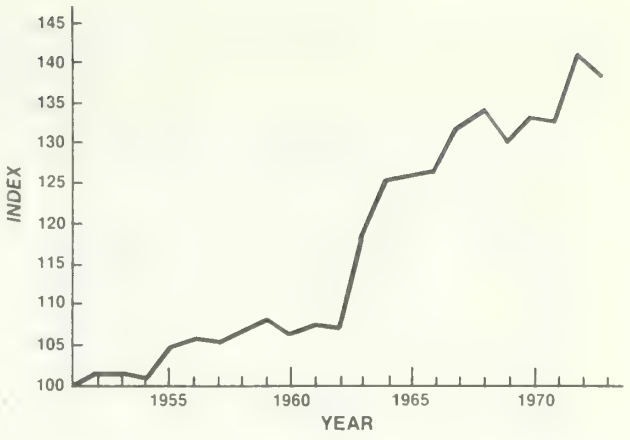


Figure 1.—*Index of total factor productivity, U.S. lumber and wood products industry, 1951-1973; 1951 = 100. Source: Bengston and Strees (1984).*

As previously mentioned, these represent the annual value of real resources saved due to more efficient production technology in this industry.

The derivation of research costs is given in table 2. Annual Forest Service expenditures for forest products utilization research were obtained from Congressional Appropriations Committee documents and Forest Service annual reports.[3] In addition to proposed research expenditures for the current year, actual expenditures for the preceding year are reported in the appropriations hearings. These are shown in the first column of table 2. Research expenditures begin and end 10 years before the calculated stream of benefits, implying a 10-year mean lag between forest products research and an impact on productivity. This assumption was based on the 8- to 10-year lag between structural particleboard research and the resulting economic benefits reported by Haygreen *et al.* (1983).

Utilization research expenditures were expressed in constant dollars using a cost of research index (Davis 1979). Notice that the amount of real scientific resources devoted to Forest Service utilization research actually declined in the years following the massive buildup of this line of research during World War II.

A rough estimate of total U.S. research on lumber and wood products—including the private sector and university research not funded by the Forest Service—was obtained by multiplying the deflated research expenditures by four. This follows the approach of Gregersen *et al.* (1983) in their evaluation

[2]*Intermediate inputs are defined as purchases of goods and services by one firm or industry from another. Examples include raw materials (e.g., wood) and fuel.*

[3]*Forest products utilization research includes research not accounted for in the calculation of benefits, such as pulp and paper. Thus, the estimated expenditures are greater than actual expenditures, and will produce conservative rates of return to lumber and wood products research.*

Table 1.--Estimation of research benefits in the U.S. lumber and wood products industry, 1951-1973

Year	A_t 1/	A'_t 2/	Q_t 3/	R_t 4/
1951	1.0000	1.0000	6,948	0.00
1952	1.0158	1.0106	6.962	73.80
1953	1.0159	1.0119	7,040	83.78
1954	1.0040	1.0234	6,711	157.04
1955	1.0504	1.0373	7,659	285.68
1956	1.0576	1.0540	7,717	416.72
1957	1.0539	1.0604	7,178	433.55
1958	1.0698	1.0695	7,525	522.99
1959	1.0849	1.0732	8,215	601.34
1960	1.0649	1.0751	8,043	604.03
1961	1.0755	1.0707	8,001	565.67
1962	1.0718	1.1092	8,432	920.77
1963	1.1804	1.1684	9,520	1,603.17
1964	1.2530	1.2298	10,010	2,300.30
1965	1.2559	1.2580	10,190	2,629.02
1966	1.2652	1.2810	10,223	2,872.66
1967	1.3220	1.3103	10,779	3,344.72
1968	1.3437	1.3214	11,046	3,550.18
1969	1.2984	1.3241	10,758	3,486.67
1970	1.3302	1.3183	11,030	3,510.85
1971	1.3263	1.3561	11,017	3,923.15
1972	1.4117	1.3735	13,132	4,904.80
1973	1.3826	1.3826	12,702	4,859.79

1/ Index of total factor productivity for the U.S. lumber and wood products industry. Source: Bengston and Strees (1984).
2/ Three year moving average of A_t.
3/ Value of production, U.S. lumber and wood products industry, in millions of 1958 dollars. Source: U.S. Department of Commerce, Bureau of Economic Analysis, unpublished data.
4/ Estimated research benefits in millions of 1958 dollars:
$R_t = [A'_t - 1] Q_t$.

of major forest products innovations. Agricultural research evaluators have sometimes multiplied public research expenditures by a factor of two to capture private expenditures (Griliches 1964, Fishelson 1971, Peterson 1971, Peterson and Fitzharris 1977).

Finally, an adjustment was made to recognize that new technologies originating outside a particular industry often have a significant impact on productivity growth within the industry. Previous aggregate research evaluations have not accounted for this potentially major source of productivity growth. Scherer (1982) has examined these interindustry technology flows using data based on patent activity in the U.S. He found that certain industries tend to "borrow" or "import" a significant amount of research results from other industries. The lumber and wood products industry was no exception. Scherer calculated a matrix of interindustry technology flows indicating that for every dollar of research and development (R&D) originating within the industry, 1.8 dollars of R&D is used. Industries such as motor vehicles and equipment, materials handling, machinery, and chemicals accounted for most of the technological innovations flowing into lumber and wood products. The adjustment of total research expenditures for interindustry technology flows is given in the last column of table 2.

Table 2.--Estimation of lumber and wood products research costs, 1942-1963

(Thousand dollars)

Year	Forest Service expenditures[1/]	1958 dollars[2/]	Expenditures[3/]	Adjustment for interindustry technology tech. flows[4/]
1942	966	2,322	9,288	16,718
1943	1,075	2,506	10,024	18,043
1944	1,064	2,254	9,016	16,229
1945	1,144	2,460	9,840	17,712
1946	1,402	2,850	11,400	20,520
1947	1,536	2,893	11,572	20,830
1948	1,243	2,114	8,456	15,221
1949	1,179	1,946	7,784	14,011
1950	1,187	1,815	7,260	13,068
1951	1,266	1,798	7,192	12,946
1952	1,261	1,675	6,700	12,060
1953	1,246	1,556	6,224	11,203
1954	1,207	1,418	5,672	10,210
1955	1,256	1,394	5,576	10,037
1956	1,565	1,623	6,492	11,686
1957	1,927	1,875	7,500	13,500
1958	2,402	2,402	9,608	17,294
1959	2,618	2,395	9,580	17,244
1960	2,854	2,501	10,004	18,007
1961	3,527	2,954	11,816	21,269
1962	4,477	3,562	14,248	25,646
1963	4,822	3,678	14,712	26,482

1/ Forest products utilization research expenditures in current dollars. Sources: (1) Department of the Interior and related agencies appropriations for (various years), hearings before a subcommittee of the Committee on Appropriations, House of Representatives. (2) Department of Agriculture appropriations for (various years), hearings before the subcommittee of the Committee on Appropriations, House of Representatives. (3) Report of the Chief of the Forest Service, Statistical Supplement (various years).

2/ Forest Service forest products utilization research expenditures deflated by a research price index (Davis 1979, p. 138).

3/ Estimated as four times Forest Service expenditures. Includes estimated expenditures by firms, universities, and other public agencies.

4/ Estimated as 1.8 times total expenditures (see text).

RESULTS

Internal rates of return were calculated for the investment in U.S. lumber and wood products research over the period 1942 to 1973. It was found that this line of research has been highly profitable from society's point of view. A return of 40 percent was calculated when estimated total research costs (not adjusted for interindustry technology flows) were compared to research benefits. When the estimated cost of developing technologies used in forest products but originating in other industries is included, the rate of return is 34 percent.

DISCUSSION

A frequent theme in the agricultural research evaluation literature is that the high rates of return compared with most other types of investments indicates an underinvestment in agricultural research. There is a fallacy in this argument, however, as pointed out recently by Fox (1984). Research evaluators have calculated social returns and compared these with the private returns obtainable by firms. But social and private returns are incommensurate. In fact, Peterson (1976) has shown that the social rate of return to private research is necessarily higher than the private return. Conclusions about a general underinvestment in forest products research therefore cannot be drawn from this study.

Furthermore, the average rates of return calculated in this study preclude the use of the results in research resource allocation. Average rates of return to research investments are helpful in better understanding the economic impacts of R&D. In research decisionmaking, however, marginal decisions may be made at any juncture. A marginal rate of return—providing information about the return to additional investment—is therefore the appropriate economic measure for comparing the merits of alternative research projects or programs.

What general conclusions can then be drawn from the relatively high rates of return to lumber and wood products research? First, investment in this type of research has been socially profitable. The gains to society stemming from this research have been substantial compared with costs.

Second, returns to lumber and wood products research compare favorably with returns to aggregate agricultural research. Peterson (1971) calculated an average rate of return to U.S. agricultural research over the period 1910 to 1967 of 19 percent. To be strictly comparable, similar time periods for the two investments should be considered. Although not directly comparable, estimated marginal rates of return to aggregate agricultural research have generally been found to be in the range of 35 to 40 percent (Griliches 1964). Some aggregate-level evaluations have found higher marginal rates of return for certain periods (Evenson *et al.* 1979, Davis and Peterson 1981), while others have found lower returns (Latimer and Paarlberg 1965, Fishelson 1971).

The aggregate rates of return calculated in this study are also of the same order of magnitude as the average returns found in previous forest products research evaluations. Gregersen *et al.* (1983) found rates of return ranging from 18 to 30 percent when the benefits of several major forest products innovations were compared with estimated total forest products research expenditures. Bengston (1984) found average returns to structural particleboard research in the U.S. of 19 to 22 percent.

Several issues have been raised in this paper which require further attention. Perhaps most interesting is the question of accounting for the costs of interindustry technology flows in evaluating research at an aggregate level. This is less likely to be a concern in a case study evaluation of a specific innovation, but at the aggregate level it is clear that innovations originating in one industry may be a major source of productivity growth in another. A current example is the proliferation of specialized microcomputer technology and its impacts on the productivity of timber processing, farm management, etc. Attributing all productivity gains to research carried out within an industry may result in a substantial upward bias in the returns to research. Evaluations of agricultural research have not adjusted research expenditures for interindustry flows, even though industries such as pharmaceuticals (other than agricultural chemicals), rubber and plastic products, machinery (other than farm machinery), and motor vehicles and equipment have been important sources of innovations used in agriculture (Scherer 1982).

A related issue is the impact of international technology flows on productivity. Very little work has been carried out in this specific area, although a large body of literature exists on international technology transfer (Sagafi-nejad and Belfield 1980). In most cases, technological imports would not affect rates of return to research. The accounting stance of most research evaluations is a particular country, so research costs incurred outside of the country are not relevant. The costs of bringing the technology into the country should be included, however, and Mansfield (1975) has shown that international technology transfer is by no means costless. In addition, Mansfield *et al.* (1982) have pointed out that U.S. firms carry out a significant amount of research abroad that has an effect of productivity growth in the U.S. If these research expenditures are borne by the U.S. parent firm, they should also be included in an evaluation.

Another unresolved issue in the evaluation of forest products research is the appropriate length and shape of the time lag for the impact of research expenditure on output. This is an issue usually discussed in production function research evaluations, but information about the research lag must be included in other types of evaluations as well. Davis (1980) has reviewed alternative research lag structures used in agriculture. Empirical work is needed

in forest products to determine the length and distribution of the research lag. Research on the diffusion of innovations in forest products (Globerman 1976, Stier 1983) may be useful in this endeavor.

Finally, an important question in aggregate research evaluation relates to the inclusion of private research expenditures. Peterson (1976) has argued that since firms capture a return to their R&D by charging higher prices for their output, there is a "...double counting of the cost of private R&D when assessing the social rate of return to this investment". The cost would be included "...once on the cash outflow side and would appear again on the return side as a reduction in cash inflow (social returns)". This issue obviously has important implications for the way in which research costs should be treated, and deserves more attention. Assuming that private research expenditures in lumber and wood products are half the estimated total, the rate of return to this research increases to 47 percent when private costs are omitted. Note that it would be inappropriate to adjust research expenditures for interindustry technology flows if Peterson's argument is valid. If private research costs within an industry should not be included on the expenditure side to avoid double counting, then private costs incurred in other industries should also be excluded—that is, firms in technology "exporting" industries capture a return to their research investments by charging higher prices to the "importing" industries.

CONCLUDING COMMENTS

This paper has illustrated the use of a relatively simple approach to evaluating aggregate research investments. The index number approach described here is quite "user friendly"—the methodology is easily grasped by evaluators and by the intended users of evaluation results, unlike many other research evaluation methods. In addition, data requirements are light. This may be a particularly important factor in attempts to develop evaluation methods for forestry and forest products research, where the availability of data is often a critical problem.

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DIFFUSION OF INNOVATIONS IN FORESTRY AND FOREST PRODUCTS: REVIEW OF THE LITERATURE[1]

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The impacts of new technologies on society depend on the extent to which the technologies are utilized and the pattern of their adoption over time. Information about the diffusion of innovations is therefore fundamental to the evaluation of research. A large amount of work has been done in this area: The processes by which innovations are diffused throughout social systems have been studied extensively by scholars in many fields. Thousands of empirical and theoretical investigations into the diffusion process have been carried out over the past several decades (Rogers *et al.* 1977).

Most research evaluations have used simple assumptions to project the spread of innovations over time, and in some cases the calculated rates of return to research investments are highly sensitive to these assumptions. Although sophisticated diffusion models do not guarantee more reliable results, it is clear that forestry research evaluators could benefit from taking a closer look at what is known about the diffusion of innovations.

For example, the diffusion of containerized forest tree seedlings has proceeded much more slowly in the United States than in Canada and Scandinavia (Westgate 1984). About 50 percent of all planting stock is containerized in Canada and Scandinavia, but containerized seedlings account for only 6 percent of U.S. production. Understanding the factors that have created this large difference in adoption levels and thereby speeding up the diffusion process would have a significant impact on the returns to containerized seedling research.

This paper reviews and assesses the diffusion of innovations literature with a special focus on the forest-based sector. It is organized into three sections. First, to make sense of this broad-ranging and multidisciplinary area of study, a framework for interpreting diffusion research is presented: Diffusion research is characterized by several descriptive continua and three major traditions of diffusion research are identified and briefly described. The second section consists of a review of forestry and forest products diffusion research, with studies grouped according to their respective research tradition. A concluding section discusses the implications of this review and needs for future work in this area.

One caveat is in order before proceeding. Many studies have been carried out that examine the characteristics of forest landowners in relation to their use of various forestry management practices. These studies are in some ways similar to diffusion of innovation studies, but they remain outside the scope of diffusion research because they do not employ the distinctive conceptual models developed by researchers in this area. To keep the focus on the diffusion literature per se, these studies will not be considered in this review.

A FRAMEWORK FOR DIFFUSION RESEARCH

Many different types of diffusion research can be identified. Figure 1 characterizes diffusion research according to three continua, which cover the most prominent and relevant features of diffusion research. First is the individual/aggregate adoption continuum. Research on individual adoption is concerned with the processes by which an individual adopting unit (a person, firm, or organization) decides to adopt or reject an innovation. The focus is on the individual decisionmaking process and the relevant characteristics of the adopting or rejecting units. Researchers in fields such as sociology, communications, anthropology, and psychology have tended to concentrate on individual level adoption.

At the other end of the spectrum, "Aggregate adoption is measured by the aggregate level of use of

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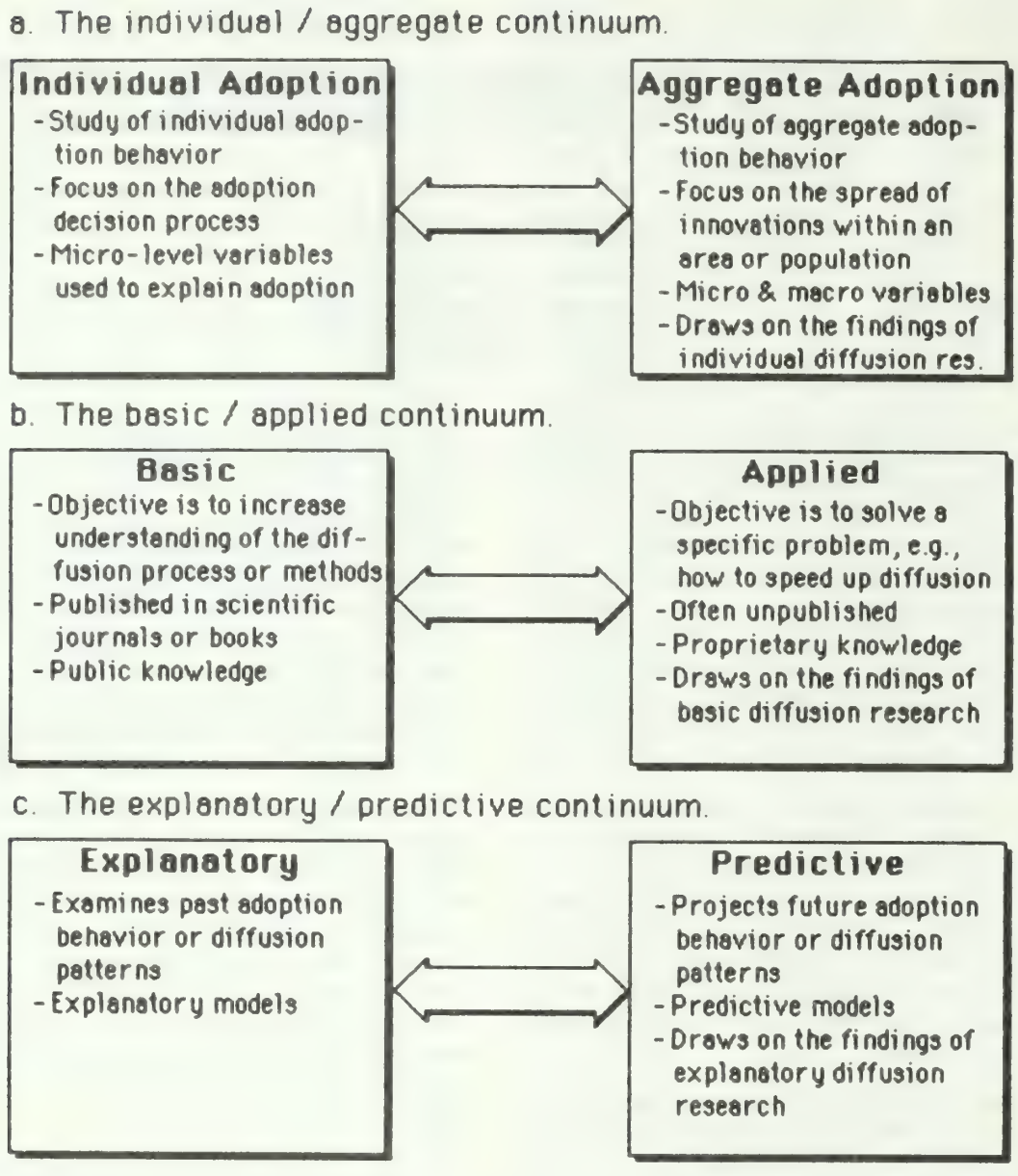


Figure 1.—*Three diffusion research continua.*

a specific new technology within a given geographical area or within a given population" (Feder *et al.* 1982). Studies of this type often try to explain the pattern of adoption of an innovation over time. Aggregate adoption research builds on the microfoundation provided by individual adoption research, but in addition to characteristics of the adopting unit, characteristics of the innovation and the environment in which diffusion takes place are often considered as explanatory variables. Economists and geographers have typically concentrated on aggregate level adoption.

A second way of categorizing diffusion research is along the basic/applied continuum, as shown in figure 1b. Basic diffusion research is aimed at increasing understanding about the processes underlying diffusion. Theoretical models of diffusion which are not tested empirically would be included at this end of the continuum.

The theories of basic diffusion research are tested empirically by applied researchers. Applied diffusion research has the objective of answering specific questions regarding case studies. For example, an analyst might be interested in estimating the eventual market share that will be captured by an innovation, measuring the rate of adoption, or identifying important factors in the diffusion of a given innovation.

Finally, diffusion research may also be characterized as falling along an explanatory/predictive continuum. Explanatory models examine past adoption

behavior or diffusion patterns. Independent variables are chosen which provide the best explanation of the observed behavior. A classic example is Mansfield's (1961) study of industrial innovations.

Predictive diffusion models, on the other hand, attempt to forecast certain diffusion variables, such as the rate of diffusion or the level of adoption. Independent variables are chosen to be useful for predictive purposes, i.e., they must be observable during the early stages of diffusion. See Martino *et al.* (1978) for an example.

As a means of further organizing the diffusion literature, Kelly and Kranzberg (1978) have suggested that diffusion research may be divided into three overall traditions on the basis of similarity in conceptual structure and methodology: sociology-psychology (S/P), economics, and geography. Several characteristics of each tradition are summarized in figure 2. The S/P tradition of diffusion research includes a number of academic disciplines, including anthropology, communication, psychology, and sociology. Inclusion of these disciplines makes this the oldest and by far the largest body of diffusion research.

Several common threads bind the S/P tradition together. First, the diffusion of innovations is viewed as a process that can be explained primarily by social, cultural, and psychological variables. The attitudes and sociocultural characteristics of adopters are often stressed as the most important factors in determining adoption behavior. Thus, work in the S/P tradition has a strong tendency toward the individual adoption end of the individual/aggregate continuum. Another common trait of this tradition is general agreement on the importance of social networks in the diffusion process. A classic example is the 1957 study by Coleman *et al.*, which explored the influence of social networks among physicians on their adoption of a new drug.

Finally, a common conceptual underpinning of the S/P tradition is provided by the "classical" diffusion model. As formulated by Rogers (1983), the classical model represents a synthesis of the approach to diffusion research that originated in the early 1940's with the work of rural sociologists Ryan and Gross (1943). In its quintessence, the classical model consists of four basic elements thought to be central to the diffusion process: "(1) an innovation, (2) communicated via certain channels, (3) to members of a social system, and (4) who adopt it over a period of time" (Rogers and Eveland 1978). A detailed treatment of each element is given in chapters 2 through 11 of Rogers (1983).

Economists have also brought their perspective to bear on the diffusion of innovations. The work in this area has been much more limited and recent than the S/P tradition, with the first economic study appearing in 1957 (Griliches 1957). Four main fields of

Research Tradition / Characteristics	Sociology/ Psychology	Economics	Geography
Main Disciplines	Anthropology Communication Psychology Sociology	General Economics Agricultural Econ. Marketing Tech. Forecasting	General Geography Economic Geography
Individual/ Aggegate Adoption	Focus on individual adoption.	Focus on aggregate adoption.	Focus on aggregate adoption.
Explanatory /Predictive	Focus on explanatory models.	Explanatory and predictive models.	Focus on explanatory models.
Common Variables	Social, cultural, and psychological variables.	Economic variables.	Spatial and economic variables.
Major Empirical Studies	Ryan & Gross (1943) Coleman et al. (1957)	Griliches (1957) Mansfield (1961)	Hagerstrand (1952)

Figure 2.—*Summary of diffusion research traditions.*

study are included in the broadly defined economics tradition of diffusion research: general economics, agricultural economics, technological forecasting, and marketing.

Several generalizations about the economics tradition may be ventured. First, the diffusion of innovations is viewed as a process that can be explained mainly by economic variables. Economic variables considered most frequently include profitability and size of the initial investment required to adopt an innovation. These are two aspects of relative advantage, a much broader explanatory variable that has been examined by diffusion researchers in each of the three traditions.

Economists have also tended to focus on aggregate adoption. This concentration on the aggregate level is in contrast to the S/P tradition in which the decisionmaking process involved in individual adoption is often stressed. Different research approaches and models have been used to focus on aggregate adoption. Instead of personal interviews and detailed sociometric data, economists have usually relied on secondary data and econometric models to test their hypotheses concerning diffusion.

The third major stream of diffusion research is the geographer's tradition of spatial diffusion—that is, "The relationship between the innovativeness of adopters and their relative position in physical space" (Kelly and Kranzberg 1978). Geographers have studied the diffusion process through most of this century (Brown 1981). The early work in this area was carried out by cultural geographers whose main concern was the role of the spread of innovations in shaping the cultural landscape. Geographic diffusion research took a different tack following the pathbreaking work of Swedish geographer Torsten Hagerstrand in the early 1950's. A new group of geographers—trained mainly in economic and urban geography—were inspired by Hagerstrand to investigate the diffusion process.

Several generalizations about the geographic tradition may be made. First, the physical proximity of potential adopters is stressed as a variable to explain observed diffusion patterns. Researchers in the geography tradition have also investigated other variables, termed receptivity factors, which are thought to modify the spatial pattern and rate of adoption of innovations. These include the adopter's attitudes and values, cost of adoption, returns to adoption, and the role of self-interested innovation propagators (Hagerstrand 1968).

Like many researchers in the economics tradition, geographers have tended to focus on adoption at the aggregate level. According to Hagerstrand (1968), the geographers have been concerned with various "macro-concepts" such as "growth curves, centers of innovation and centers of spread, channels of diffusion, barriers to diffusion, cultural boundaries, and regional differences in receptivity."

The standard conceptualization of spatial diffusion—developed by Hagerstrand—is based on the idea that the adoption of an innovation is the outcome of a learning or communication process (Brown 1981). This is congruent with the basic tenets of the S/P tradition. As a means of testing this conceptualization, Hagerstrand introduced Monte Carlo simulation techniques to model the diffusion process over time and space (Hagerstrand 1967). This innovation in diffusion research has been adopted by many researchers in the geography tradition.

DIFFUSION RESEARCH IN FORESTRY AND FOREST PRODUCTS

In this section diffusion research in the forest-based sector will be reviewed and characterized according to the framework presented in the preceding section. Empirical and non-empirical studies of the diffusion of forestry and forest products innovations will be reviewed as comprehensively as possible. Sociology/psychology, economic, and geographic studies will be grouped separately to facilitate evaluation.

The Sociology-Psychology Tradition

Several studies have examined the diffusion of forestry innovations from the S/P perspective. Most of these have been carried out by rural sociologists. Perhaps the first forestry diffusion study of this type was an analysis of the adoption of improved forestry practices by nonindustrial private forest land (NIPF) owners in Louisiana (Bertrand and South 1963). The classical diffusion model provided the conceptual underpinning for this study. Bertrand and South were primarily interested in determining the characteristics of small woodland owners related to their propensity to adopt recommended forestry practices. Diverse forestry practices were chosen as the innovations to be studied, including pruning trees, fencing out livestock, constructing fire guards, preparing ground for natural seeding, using a written contract for selling wood, and seeking advice from professional foresters. The results of the analysis were summarized as follows:

> Those characteristics found to be related positively to adoption of woodland management practices were: a progres-

sive attitudinal orientation; a median age (40-59); white race; male sex; the attainment of higher education (up through high school); larger-sized holdings both total and in woodlands; the perception of benefits derived from woodlands; upper socioeconomic rank; a mixed farming enterprise; full-time farming; and residence in Washington Parish.

It was concluded that the results of this study would be useful to foresters interested in promoting new practices. Unfortunately, the usefulness of this analysis is limited by the fact that the relative importance of the above factors on the decision to adopt was not measured.

In addition, as is often the case in diffusion studies of this type, most of the factors considered by Bertrand and South have little or no relevance for public policy. Examples include the race and socioeconomic status of adopters. Public policymakers could not use these variables in the design and implementation of a technology transfer program.

Technology transfer as a field of study is closely related to diffusion research. The findings of diffusion research are often applied in technology transfer studies with the explicit goals of (1) speeding up the rate at which an innovation is adopted, (2) increasing the extent of adoption, or (3) otherwise increasing the efficiency and effectiveness of the diffusion process. Examples of technology transfer work in forestry include Moeller and Heytze (1981), Nicholls and Prey (1982), and Hobbs *et al.* (1983). Because the technology transfer literature is large and fairly distinct from the diffusion literature, it will not be considered further in this paper.

A spate of similar studies followed Bertrand and South, including Sollie (1965), South *et al.* (1965), Sollie (1967), and South (1968). Each of these studies routinely tested a series of hypotheses about the characteristics of adopters of recommended forestry practices in limited geographic areas. The conclusions reached were generally quite close to those of Bertrand and South (1963).

In addition to these empirical studies, Muth and Hendee (1980) provided an overview of the S/P tradition of diffusion research from a forestry perspective. They concluded that the findings of diffusion research could contribute significantly to the design of technology transfer programs to speed up the adoption of forestry innovations.

The Economics Tradition

Several investigations into the diffusion of forest products innovations have been carried out by economists in the past decade. These studies have looked at three types of innovations: pulp and paper, wood-based panels, and residential construction. The earliest and most comprehensive economic study was Hakanson's (1974) analysis of the diffusion of special presses used in paper making. Using an econometric model similar to Mansfield's (1963), Hakanson studied the diffusion of four different types of special presses in six countries. He hypothesized that the profitability of adoption, date of first information about special presses, firm size, and an innovativeness index would be positively related to early adoption by a firm. Hakanson found that the profitability and company size variables explained a large amount of the variability in adoption rates.

Globerman (1976) studied the diffusion of special presses in the Canadian paper industry. Two econometric models were developed to determine which factors were most important in explaining the diffusion of special presses. First, a model of inter-firm diffusion was specified and fit. It was found that higher profitability of special press adoption was positively related to early adoption, firm size was not related to time of adoption, and domestically owned firms were slower to adopt than foreign subsidiaries. Globerman also fit a model of intra-firm diffusion designed to identify factors associated with the spread of innovations within a firm after initial adoption. In this model domestic or foreign ownership was found to be unimportant in explaining the spread of special presses within a firm. Another economic study of the diffusion of innovations in the Canadian paper industry—including special presses—was carried out by Martin *et al.* (1979b).

Two paper-making innovations were included in a large diffusion study of 49 innovations in 14 industries by Martino *et al.* (1978). The kraft pulping process and computer process controls in the pulp and paper industry were examined, although the former innovation was not included in the final analysis due to insufficient data on some industry variables. The intent of this study was to develop a predictive model to forecast the rate of diffusion across industries. Conclusions specifically related to the diffusion of computer process controls in paper making cannot be drawn from this study because the data for each of the included innovations were pooled to estimate the predictive models. But the *ex ante* approach and large number of independent variables examined makes this an instructive and interesting study, particularly for researchers concerned with forecasting diffusion.

Finally, Stier (1983) examined the diffusion of the sulfate pulping process in the U.S. pulp and paper industry. Stier developed an econometric diffusion model based on the Gompertz function. An innovative feature of this model was the inclusion of a dynamic diffusion ceiling, in which the ceiling level of adoption was assumed to be a log-linear function of real product price and real gross national product. It was concluded that "most of the rapid expansion in sulfate pulp production that occurred can be attributed to upward shifts in the ceiling level of demand," and not in the "natural rate of diffusion." Projections made for the years 1990 and 2000 show that "the sulfate process will continue to capture market share and could account for over 90 percent of total U.S. woodpulp production by the year 2000."

Several economists have studied the diffusion of innovations in wood-based panels. An interesting example of international diffusion is provided by the particleboard case study by Buongiorno and Oliveira (1977). They analyzed the growth of the share of particleboard production (measured as a percentage of total wood-based panels) in 25 industrialized countries using an approach similar to that of Griliches (1957). Buongiorno and Oliveira concluded that countries in which particleboard was initially adopted slowly tended to have higher long-term ceiling levels. It was also found that eastern European countries had significantly lower ceiling levels of adoption than market economies. An econometric analysis of factors influencing the date of initial adoption in a country concluded that greater distance from the Democratic Republic of Germany (where particleboard was first produced) and the availability of large supplies of roundwood were the most important factors in delaying the time of adoption of particleboard. Finally, it was found that countries with higher economic growth and lower wood availability tended to have more rapid rates of adoption.

Leefers (1981) examined the diffusion of particleboard and southern pine plywood in the U.S. He was mainly interested in the effects of the diffusion of these panels on wood requirements in the future. Two diffusion models—the logistic and Gompertz functions—were used to estimate the potential market shares and growth rates for panel innovations. He concluded that these univariate models, while useful for depicting diffusion trends over time, were not helpful for explaining the diffusion process. Multivariate models were therefore used to identify supply and demand factors influencing particleboard and southern pine plywood diffusion.

Residential construction has been identified as a neglected sector in the study of technological change (Strassmann 1978). There have been several investigations into the diffusion of innovations in residential construction, however, including wood products innovations. Martin *et al.* (1979a) examined the diffusion of wood roof trusses in Canada. They concluded that the diffusion of roof trusses has been closely related to cycles in residential construction. This is hardly surprising, but it reinforces Stier's (1983) findings that increases in overall demand can induce much more rapid diffusion. It was also concluded that institutional constraints—such as zoning laws—are not impediments to the diffusion of roof trusses, and that proximity to large local markets is an important factor due to high transportation costs.

In a study of innovation in residential construction in the U.S. (Spall 1971), roof trusses, finger-jointed wood, and six other innovations were studied. Spall's analysis was based on interviews of the managers of 20 firms building single-family housing in Michigan. He concluded that the entrepreneur's extent of adoption was not correlated with his years of formal education, his experience in the industry, his subjective receptiveness to innovations, the size of his firm and volume of business, or the possibility of increased competition. Adoption or nonadoption was found to depend only on estimates of profitability of adoption. These findings contradict the conclusions of diffusion researchers in the S/P tradition.

Finally, a total of 14 innovations in residential construction—including, once again, wood roof trusses, several other wood-related innovations, and a variety of nonwood innovations—were examined by Ventre (1979, 1980). He considered an innovation to be "adopted" in an area when local building codes were modified to permit its use. The main finding of this study was a refutation of the common perception of the housebuilding industry as technologically backward:

> The major significant result of this analysis is to deny the technological lethargy of the building industry and the agencies that regulate it: innovations diffuse throughout the industry—despite the special characteristics cited at the beginning of this paper—in much the same way and at the same speed as in other industries (Ventre 1979).

The Geography Tradition

Judging by reviews of several large diffusion bibliographies and a bibliography of geographic diffusion studies (Harton *et al.* 1975), it appears that very little research into the diffusion of forestry and

forest product innovations has been carried out in the geography tradition. In fact, we have been unable to locate any forestry diffusion studies which employ the distinct methodological approach to diffusion research developed by geographers. There are, however, several studies by geographers which examine the spatial patterns of technical change in forestry.

Dinsdale (1965) attempted to define the changing spatial patterns in the lumber industry of northern New York State and relate these to three distinct phases of technological development. The three phases were first identified by Mumford (1934), and are summarized by Dinsdale as follows:

> The eotechnic or "dawn age" of modern technics is typified as a wood, wind, and water power complex; the paleotechnic is the coal, steam, and iron complex; and the neotechnic is briefly characterized by such features as electricity, the internal combustion engine, alloys and synthetic materials.

Dinsdale traced each of these technological phases in the lumber industry and identified the technological innovations associated with each. She concluded that each phase of the industry's development was characterized by spatial and technological patterns which conform well to Mumford's phases of the industrial revolution.

Adeyoju (1969) analyzed the development of the timber industry in Benin with a focus on the spatial and temporal spread of timber concessions, an institutional innovation. This is essentially an historical account, however, rather than a geographic diffusion case study. It was concluded that physiography, rainfall and technological developments in transportation systems were important factors in the early growth of the industry.

CONCLUSIONS AND IMPLICATIONS

Several conclusions emerge from this review of forestry and forest products diffusion research, which is summarized in figure 3. First, relatively little work has been done on forestry innovations per se. Work in the S/P and geography traditions on forestry innovations appears to be very limited. All of the research by economists has looked at innovations in forest products, probably because these innovations are quite amenable to economic analysis. But many forestry innovations relate to nonmarket activities.

Empirical Studies	Type of Innovation	Diffusion Research Tradition
Bertrand & South (1963) Sollie (1965) South et al. (1965) Sollie (1967) South (1968)	Improved Forestry Practices	Sociology/ Psychology
Hakanson (1974) Globerman (1976) Martino et al. (1978) Martin et al. (1979b) Stier (1983)	Pulp & Paper	Economics
Buongiorno & Oliveira (1977) Leefers (1981)	Wood-Based Panels	Economics
Spell (1971) Martin et al. (1979a) Ventre (1979, 1980)	Residential Construction	Economics

Figure 3.—*Summary of forestry and forest products diffusion research.*

It is clear that more research is needed to understand the diffusion of forestry—as opposed to forest products—innovations. One of the few studies contributing to this area identified 22 factors that were important in the successful adoption of forestry innovations (Moeller and Shafer 1981). The most important factors were found to be adaptation of existing technology, pilot studies to demonstrate feasibility, cooperation with private industry, and the development of underlying theory.

Another conclusion from this review of the literature is that predictive diffusion models are lacking. Forecasting the diffusion of forestry and forest products innovations would be useful to research evaluators, policy analysts, and policymakers. The only existing predictive models of diffusion developed specifically for the forest sector are Stier's (1983) model of technological substitution in the pulp and paper industry and Leefer's (1981) models for woodbased panels.

It would appear that the diffusion of innovations literature has several important limitations for application in forestry at the present time. The number of forestry-specific diffusion studies is small and the extent of the coverage is limited with respect to type of innovation studied, geographic area, etc. The potential usefulness in terms of increasing the rate of adoption and implementing technology transfer policies is restricted by the variability of research findings, the high degree of specificity, and the paucity of policy-relevant variables in existing empirical studies. Finally, usefulness of diffusion research for forecasting in forestry is limited by a shortage of predictive models.

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SUMMARY: EVALUATING RETURNS TO RESEARCH IN TIMBER-HARVESTING TECHNOLOGY

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Research in the commercial production of forest products includes a broad spectrum of subjects. Topics range from tree seedlings and regeneration to final consumer products such as housing and furniture. Timber harvesting and transportation provides an important link between the biological production of standing trees and their manufacture into primary and secondary forest products.

Project MIS-6901 of the Mississippi Agricultural and Forestry Experiment Station is designed to evaluate returns to research in timber-harvesting technology. The study of aggregate investments in timber-harvesting research will be evaluated for two major timber-producing regions, the South and the Pacific Northwest. Harvesting technologies vary significantly between these regions due to many forest-type and physiographic differences.

Most timber-harvesting research and development in the U.S. has resulted in labor-saving technical change. For this reason the initial framework for evaluation will involve *ex post* production function methods. These methods have been applied extensively in agricultural research evaluations, and involve predicting aggregate output with conventional inputs and research expenditures. Logging industry (SIC 2411) measures in the Census of Manufactures include value added and value of shipments, value of depreciable assets, new capital expenditures, and various measures of labor as possible variables for output and conventional capital-labor inputs. Secondary data are not available, however, for aggregated harvesting research. One option for the analysis involves developing and using approximate measures of regional research efforts in harvesting. Another option is to exclude research inputs and concentrate on defining productivity increases, using indirect measures to impute returns to research and development.

Production function methods can also be used to consider the distribution of research benefits over time. Several agricultural studies, for example, have assumed research benefits increase, reach a maximum, and decrease with time, and have modeled the relationship with a second-degree polynomial. The Office of Technology Assessment recently reported that 7-10 years may be required to develop new, innovative systems in timber harvesting. In the present study, problems may arise in modeling lagged research effects, since cross-sectional data are anticipated. Agricultural evaluations with similar problems will be considered in evaluating production function approaches and their application to the research lag for timber-harvesting improvements.

Preliminary results of the study should be available by the spring of 1986. The analysis will then be refined, and equity and distributional issues will be investigated.

AN ECONOMIC ANALYSIS OF A NEW GROWTH AND YIELD MODEL FOR OAKS IN NEW ENGLAND

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Oak-hickory stands cover 108,900,000 acres—some 22.6 percent of the commercial timberland in the United States. Geographically, oak-hickory stands extend in a widening band from southern New England to the grasslands of Nebraska, Kansas, Oklahoma, and Texas. Oak-hickory stands in New England cover 2,146,000 acres of commercial timberland (USDA Forest Service 1982).

Until recently, however, neither a local yield table nor a local growth and yield model of this commercially important forest type had been developed for the New England region. Land managers in New England have historically relied on Midwest guidelines (Gingrich 1971) when making management decisions. These guidelines do not accurately reflect New England conditions, and, as Hibbs and Bentley (1984) have indicated, the volume and value of oak-hickory forest in New England has increased to the point where small errors in management prescriptions can have a large economic impact. In this paper we will investigate the value of a recently published growth and yield model for oaks in New England (Hibbs and Bentley 1984).

In determining the economic value of the local growth and yield information, we considered only the direct value. Indirect effects, such as possible increases in employment, income, and the multiplier effects thereafter, were not included. Further, since the growth and yield information only addresses the question of timber volume, we limited our analysis to impacts on timber production.

MEASURING THE VALUE OF LOCAL GROWTH AND YIELD INFORMATION

Forest mensurationists and biologists would argue that gathering and developing growth and yield information is an endeavor to produce scientific knowledge. The obtained knowledge itself has its intrinsic value. From an economic point of view, however, the answer may not be so clear. Whether a growth and yield model has any value at all depends on how it affects timber management decisions. If the new information leads to better management decisions, there must be economic gains, and the new growth and yield information thus has economic value. On the other hand, if the new information does not change management decisions, there is no improvement, no economic gain, and thus no value accrued.

Just how should the economic value of the growth and yield information be measured? Since the objective of timber production is to maximize the land expectation value, it would be natural to measure the value of the local growth and yield information through changes in the land expectation value as a result of their availability. For example, if the optimal regional rotation age is 35 years when the stumpage price is $58/MBF, regeneration cost is $90/acre, and the interest rate is 6 percent, then the hypothetical local yield table (table 1) would lead to a rotation age of 33 years under the same combination of price, regeneration cost, and interest rate. The value of the local growth model, in terms of increased land expectation value would then be $10.63. This $10.63 is derived as follows: When the stand is harvested at age 35, the stand volume would be 27.5 MBF rather than the yield reported in the regional yield table. With a yield of 27.5 MBF, the value of the land would be $120.01. Once the hypothetical local yield table becomes available, the landowner would shift his rotation to 33. The land expectation value, as a result, becomes $130.40 Since the local yield data would result in a better management decision and the landowner would have gained $10.63 on a per acre basis it could be said that the $10.63 represents the value of the local yield information per acre. On the other hand, if the regional rotation were 33 then the hypothetical yield table has no economic value at all. It does not have economic value because management decisions are the same with or without it.

Table 1.--The hypothetical local yield table and the land expectation value calculation[1/]

Year	Production	Land expectation value
	boardfeet/acre	$/acre
25	10,700	62.40
26	12,000	71.22
27	13,400	79.55
28	15,100	90.00
29	17,100	101.98
30	19,200	112.71
31	21,400	122.51
32	23,500	128.69
33	25,300	130.64
34	26,600	127.14
35	27,500	120.01

1/ Assumptions for calculation of LEV:
Stumpage price, P(t), = $58 per thousand boardfeet
Regeneration cost, c, = $90 per thousand boardfeet
Interest rate, r, = 6%

THE VALUE OF THE LOCAL GROWTH AND YIELD MODEL FOR OAK STANDS IN NEW ENGLAND

Typically, oak stand management is divided into two phases (Holsoe 1933). In phase I, during which the most rapid growth in total tree heights occurs, high stand density is maintained to promote natural pruning of branches and consequently rapid increase in merchantable height. In phase II, stand density is reduced periodically by thinning to allow unconstrained crown growth and accelerated stem diameter growth.

We would argue then that if the new growth and yield model led to choices for phase I length, phase II length, and after-thinning growing stock levels different from those indicated by the Midwest guidelines, such a model has indeed had economic value. On the other hand, if all management decisions remain the same with or without the new growth and yield model, then the new model basically has no economic value.

Over the years, the Midwest guideline represented the *de facto* regional yield table. All management decisions were based on the yield information contained therein. As the first step in measuring the value of a local yield model for oak in New England, the optimal management regime under the Midwest guideline must be determined. To facilitate later comparison with the results from Hibbs' and Bentley's study, the same price, precommercial thinning cost, and interest rate were used to determine the length of phase I period and final harvest age. Cordwood price was assumed to increase linearly from $5 to $10 per cord as d.b.h. increased from 5 to 10 inches, and to remain constant at $10 per cord for trees above 10 inches d.b.h. Saw log stumpage price was assumed to increase linearly from $120/MBF to $300/MBF as d.b.h. increased from 12 to 30 inches, and then remain constant. The precommercial thinning cost was assumed to be $50 per thinning (a thinning is considered precommercial when the stand diameter is less than 5 inches). Interest rate was assumed to be 4.5 percent.

Based on the yield table in Gingrich's (1971) study, the optimal combination of phase I length and final harvest age for a site index 65 oak stand is 30 and 80 years, respectively. When this combination is applied to the growth and yield model for upland oak stands with the same site index in New England, the land expectation value is only $52.16 per acre (Hibbs and Bentley 1984). The optimal combination of phase I duration and final harvest age for New England, on the other hand, is 45 and 95 years, respectively. The land expectation value in this case equals $100.81 per acre. Therefore, it can be said that the value of the new growth and yield model equals $48.65. However, it must be pointed out that this $48.65 represents the value of the new model when the stumpage price, interest rate, and precommercial thinning cost are as described earlier. What happens to the value of the growth and yield information when these parameters change? The most likely

changes are summarized below (it is possible that these statements will not hold true in all cases):

1. The higher the stumpage price, the higher the value of growth and yield information.
2. The higher the precommercial thinning cost, the lower the value of the growth and yield information.
3. The higher the interest rate, the lower the value of the growth and yield information.

MEASURING THE BENEFIT/COST RATIO OF GROWTH AND YIELD STUDIES

When we examine the benefit/cost ratio of a particular growth and yield study, additional considerations enter into both the benefit and cost sides of the computation. On the benefit side, there is first the question of the level of adoption—the higher the level of adoption, the higher the total benefit. Second, there is the question of timing of the adoption; obviously, the earlier the adoption the greater the benefit. On the cost side, we have to consider not only the cost of the study itself, but also the cost of disseminating the results. If the ultimate users are not aware of the research results, then there will never be any adoption.

In the case of the oak growth and yield study for New England, we made the following rough estimates. First, based on conversations with experienced foresters, we assumed a site index of 65 is average for all oak sites in New England. Second, we assumed that landowners would adopt the new management regime on only one-fourth of the oak sites. We further assumed that the rate of adoption is such that the overall benefit will be further reduced by three-fourths. Based on these rather conservative estimates, the total benefit of this oak growth and yield study equals

$$\$48.65 \times 2{,}146{,}000 \times 0.25 \times 0.25 = \$6{,}525{,}181.20.$$

While we do not have the actual cost of the project, it has to be less than $400,000 (roughly 3 years' worth of the entire McIntire-Stennis fund for Connecticut). A benefit/cost ratio of 16.31 certainly would be highly acceptable to any research administrator.

CONCLUSION

In this study, we examined the impact of the newly published oak growth and yield model for New England. Highly favorable results were obtained because:

1. There was no real regional yield table for oaks in New England, and they grow quite differently from oaks in the Midwest.
2. There is a very substantial acreage of oak in New England.
3. The stumpage price for oak is high.

Based on these observations, it would seem prudent in the future to follow a research strategy that favors growth and yield studies of:

1. Those species without a true regional model.
2. Those species with a large acreage.
3. Those species with high stumpage value.
4. Those species with low regeneration and other silvicultural costs.

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RESEARCH EVALUATION TECHNIQUES APPLIED TO A CASE STUDY OF SHORT-ROTATION FORESTRY

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The forestry community has planned and conducted forestry research for well over 100 years, and continues to provide new information and technologies for managing and using forest resources. Yet, we have only a shallow understanding of the decision making processes within forestry research and the organizational structure of researchers within the broader forestry community. We also lack systematic methods for evaluating the effectiveness and efficiency of forestry research.

As part of the larger U.S. Forest Service program in research evaluation, we recently studied the research process within one area of endeavor—short-rotation forestry. This case study was undertaken by Fege and Brown (1984) to document the resources invested and the results obtained from 1966 to 1982, to identify factors that influenced the development of this area of research, and to evaluate efforts to implement research results.

Three aspects of that case study are described in this paper: the relationships between funds and publications on an annual basis, as measures of research inputs and outputs; the relationships between total funds and publications; and the level of participation of investigators from one 5-year period to the next, as measured by funds and publications. In addition, the availability of data is addressed as well as the applicability to forestry research of various research evaluation methods used in the case study. Other aspects of the case study reported elsewhere include a survey of individual researchers to identify their reasons for conducting research in short-rotation forestry, the use of publications to describe the organizational structure of this research community, and an assessment of short-rotation technology development (Fege and Brown 1984).

The research effort in short-rotation forestry exhibits several attributes that are characteristic of forestry research in general, making this area of research a good choice for a case study. These attributes include: (1) an interdisciplinary approach; (2) an urgency attached to the initial research efforts and a relatively rapid infusion of funds, similar to that in the Forest Service's spruce budworm or southern pine beetle programs; (3) the involvement of several funding and performing agencies outside of the Forest Service and forestry schools, similar to that in acid rain research; (4) the ability to apply a body of basic information and known research methods in addressing the research questions; and (5) the involvement of both "well-established" and "new" researchers. Short-rotation forestry also lends itself well to a case study on the research process because the concept can be defined fairly narrowly, all research has been conducted since the concept was defined in 1965, most investigators are still active in forestry research or administration, and no specialized training exists or is necessary for "entry" into short-rotation forestry research from other disciplines.

There have been many definitions of short-rotation forestry and many phrases used to describe the same concept: short-rotation hardwoods, silage sycamore, minirotation forestry, intensive culture, silvicultural biomass farms, and energy plantations. For this study, we used the following commonly accepted definition: genetically improved planting stock established at spacing of 2×2 m or less, managed by intensive cultural techniques to optimize total biomasss production, harvested and regenerated at least every 10 years, and used for energy, pulp, or reconstituted wood products.

AVAILABILITY AND RELIABILITY OF DATA

The delineation of research directly or indirectly relating to short-rotation forestry was difficult, even though we thought that we had selected a fairly narrow, well-defined area of forestry research. Many of the problems encountered in collecting data for any research evaluation are related to the definition of research area. Whether the data are needed for the evaluation of a narrow field, such as short-rotation

forestry research, or a larger field, such as silviculture or forest management, it is always difficult to decide which information is peripheral and therefore should be excluded.

We used investigator groups as our unit of analysis for the aspects of the case study described in this paper. Research is commonly undertaken by groups of several scientists, technicians, and graduate students. Publications are commonly authored by one or more of these individuals plus graduate students and other contributing researchers. We found data on publications relatively easy to obtain. The initial list of publications was expanded by asking for additions and corrections from individual investigators, and further expanded with a list compiled by Oak Ridge National Laboratory scientists (Jack Ranney, personal communication). After selecting the publications, we analyzed literature citation patterns and coauthorship patterns in the case study (Fege and Brown 1984).

It is always difficult to identify the source and amount of funds allocated to a specific research area. The most reliable data on sources of funding were obtained from researchers, but the discrepancies in accounting procedures among universities and agencies limited the accuracy of funding level information. Researchers often report only operating costs, whereas the total funds allocated include indirect costs and salaries. As a practical matter, most scientists are conducting several lines of research at any given time, and may commit time and resources to studies that are slightly peripheral to the research for which they are receiving funds. In return, the scientist may write the final publications for a line of research when he or she is receiving funds for an entirely new area of research. Also, it is particularly difficult to identify research efforts within interdisciplinary fields such as watershed management or silvicultural control of various forest pests. Large research projects, such as the larger multifunctional research work units in the Forest Service, may be working on several problems at once and cannot isolate the funds dedicated to any one species or silvicultural method. Furthermore, research that can be applied to several species or stand types or pest groups cannot be separated, and errors in funding estimates are generated when someone arbitrarily assigns the funds to individual species or pests.

PERFORMANCE OF INVESTIGATOR GROUPS

Since a research group generally has a longer life than any one of the individual members, we chose to evaluate the publications of entire groups of investigators as part of the case study. Within our detailed study of 436 articles on short-rotation forestry published between 1966 and 1982 (Fege and Brown 1984), key words were used to identify the research group responsible for each publication. The pattern of published research results rarely parallels the pattern of funding received by a group of researchers. As table 1 shows, one investigator group published short-rotation articles for 4 years before receiving funds designated for this research; two groups were funded by as many as four agencies in 1 year; other groups (not illustrated in table 1) received funds from only one agency during their research in short-rotation forestry. In general, groups at land grant universities received funds from the greatest number of sources.

We assessed the contributions of 21 investigator (each indicated by a letter) groups by several different evaluation techniques. Table 2 shows the rank of each group on one measure of input (year of first funding) and therefore the same rank within a column (groups joined by a vertical line are listed alphabetically). To simplify interpretation, dotted lines mark the groups that had fairly similar rankings within the higher rank numbers. Table 3 shows the relative rank of each group on three measures of input (year of first funding, total number of years of funding, and total funds received).

Groups identified as B, C, and R consistently had low rank numbers, indicating a greater number of publications or more funds or earlier entry into the field of short-rotation forestry. An entire block of groups—G, I, J, L, N, and Q—was consistently ranked higher than the average group (within the dotted lines in tables 2 and 3). Groups A, D, and E received the lowest total funding, but groups A and E were among the groups receiving funds for the greatest number of years. All three groups, however, were among those with the greatest number of publications and earliest date of first publication. Groups F, O, and T had the smallest number of publications (four or fewer total publications in short-rotation forestry), yet groups F and O were among the groups with the highest total funding. Groups H and S were among the first to receive funds and received funds for more years that the average group, but these two groups were average with respect to the year of first publication and number of publications. Group K had the second largest number of publications, but otherwise was within the "average" range marked by the dotted lines. Group M wrote more publications and received more funds than the average group, but entered short-rotation forestry research later and received funds for fewer years.

Table 1.--Funding levels[1/] and publications[2/] for selected investigator groups, by year and funding agency

Investigator Code[3/]	Year													
	67-68	69	70	71	72	73	74	75	76	77	78	79	80	81
B	1		1					1	4	1	3	4	1	
		a	a	a	a						a	a	a	a
											ee		eee	eee
		s	s	s	s						s	s	s	s
													oo	oo
C	1		2	1	1	4		3	12	6	12	9	2	6
									eee	eee	eee	eee	eee	eee
				ff	ff	ff	fff	fff	fff	fff	fff	fff	fff	fff
D					3	2	2	1	2	2		8	4	7
									aa	aa	aa	aa	aa	aa
											ee	ee	ee	ee
H											3	2	2	2
			a	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa	aa
											ee		ee	ee
									o	oo	oo	oo	oo	
N												1	3	3
										a	aa	aa	aa	aa
											ee	ee	ee	ee
													o	o
R	1			2	2	2	3		3	1	3	1	5	4
										eee	eee	eee	eee	eee
	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss
									1			1	4	
						a	a	a	a	aa	aa	aa	aa	a
											ee			
					i	i	i	i	i	i	ii	ii	i	i
					s	ss	ss	ss	s	ss	ss	ss	ss	ss

1/ Funding levels indicated by letters. Codes for funding agencies and levels of funding.

a = Agricultural experiment station
e = U.S. Department of Energy
f = U.S. Forest Service
i = Industry
o = Other agencies
s = State funds

single letter=$500 to 10,000/year
two letters=$10,001 to 100,000/year
three letters=$100,000 or more/year

2/ Number of publications indicated by number

3/ Letters represent separate groups of investigators (not identified in article). Same codes used for investigator groups in other tables and figures.

Table 2.--Ranking of short rotation forestry investigator groups, by year of first funding, year of first publication, and total number of publications

Rank	Year of first funding[1/]	Year of first publication[2/]	Total number of publications[3/]	Year of first funding
1	R[4/]	P	C	R
2	P	R	K	P
3	B	B	R	B
4	H	C	D	H
5	C	A	B	C
6	S	D	M	S
7	A	K	A	A
8	E	E	E	E
9	L	S	U	L
10	J	F	N	J
11	N	G	H	N
12	F	H	I	F
13	G	I	J	G
14	I	M	S	I
15	K	N	P	K
16	M	O	Q	M
17	O	Q	L	O
18	Q	J	G	Q
19	T	L	O	T
20	U	U	F	U
21	D	T	T	D

1/ Groups with lower rank numbers received their first funds for short rotation forestry research earlier than groups with higher rank numbers.

2/ Groups with lower rank numbers published their first article on short rotation forestry earlier than groups with higher rank numbers.

3/ Groups with lower rank numbers published more articles on short rotation forestry than groups with higher rank numbers.

4/ Letters represent separate groups of investigators (not identified in the article). Same codes used for investigater groups in other tables and figures. Lines drawn between the letters representing each group show relationships between the measures. Dotted lines mark groups that had fairly similar rankings with the higher rank numbers. Vertical lines indicate those groups with the same values (such as year of first funding) and therefore the same rank within a column.

STRUCTURE OF THE RESEARCH COMMUNITY

Our efforts to represent the structure of short-rotation forestry research graphically were inspired by some of Derek de Solla Price's work (personal communication) and by techniques developed to evaluate science citations (Garfield 1979). De Solla Price refined a concept of an "invisible college" or cluster of researchers: most communication between researchers occurs within a group of about 100 people. He suggested that the structure of research areas could be represented by relationships among researchers, such as citation maps and maps of coauthorship patterns. In discussing the specific structure of the short-rotation forestry community, one colleague familiar with this community (David Fege, personal communication) suggested to us that some researchers had always been in the "in" group, and some had always been on "the fringe." We translated this observation into "participation maps," to

Table 3.--Ranking of short rotation forestry investigator groups, by year of first funding, total number of years with funding, and total funds received

Rank	Year of first funding[1/]	Total number of years with funding[2/]	Total funds Received[3/]	Year of first funding
1	R[3/]	R	C	R
2	P	H	R	P
3	B	C	F	B
4	H	B	M	H
5	C	E	B	C
6	S	S	H	S
7	A	L	J	A
8	E	J	N	E
9	L	A	O	L
10	J	N	U	J
11	N	F	P	N
12	F	G	G	F
13	G	I	S	G
14	I	K	T	I
15	K	M	I	K
16	M	O	K	M
17	O	P	L	O
18	Q	T	Q	Q
19	T	U	D	T
20	U	Q	A	U
21	D	D	E	D

1/ Groups with lower rank numbers received their first funds for short-rotation forestry research earlier than groups with higher rank numbers.

2/ Groups with lower rank numbers received funds for short rotation forestry research during more years than groups with higher rank numbers.

3/ Groups with lower rank numbers received more funds for short rotation forestry research during the years 1967 to 1982 than groups with higher rank numbers.

4/ Letters represent separate groups of investigators (not identified in the article). Same codes used for investigater groups in other tables and figures. Lines drawn between the letters representing each group show relationships between the measures. Dotted lines mark groups that had fairly similar rankings with the higher rank numbers. Vertical lines indicate those groups with the same values (such as year of first funding) and therefore the same rank within a column.

express the participation of investigator groups in funding and publication over time (figs. 1 and 2).

We characterized the level of participation of each investigator group by the annual funding level and the number of publications within a 5-year period. We named these various categories "IN," "OUT," and "FRINGE," and assigned each group's level of participation to one of these categories. Investigators with the most funds and publications were considered "IN" and those without funds or publications were considered "OUT." We assigned the "FRINGE" category to those investigators receiving very small amounts of money for short-rotation forestry, or publishing only a few articles within a 5-year period. Twenty-one investigator groups are represented in these figures by letters; these letter designations were also used in tables 1 and 3. Group C was one fund-receiving entity but included four distinct subgroups of researchers who published frequently; these were separately designated C1 through C4.

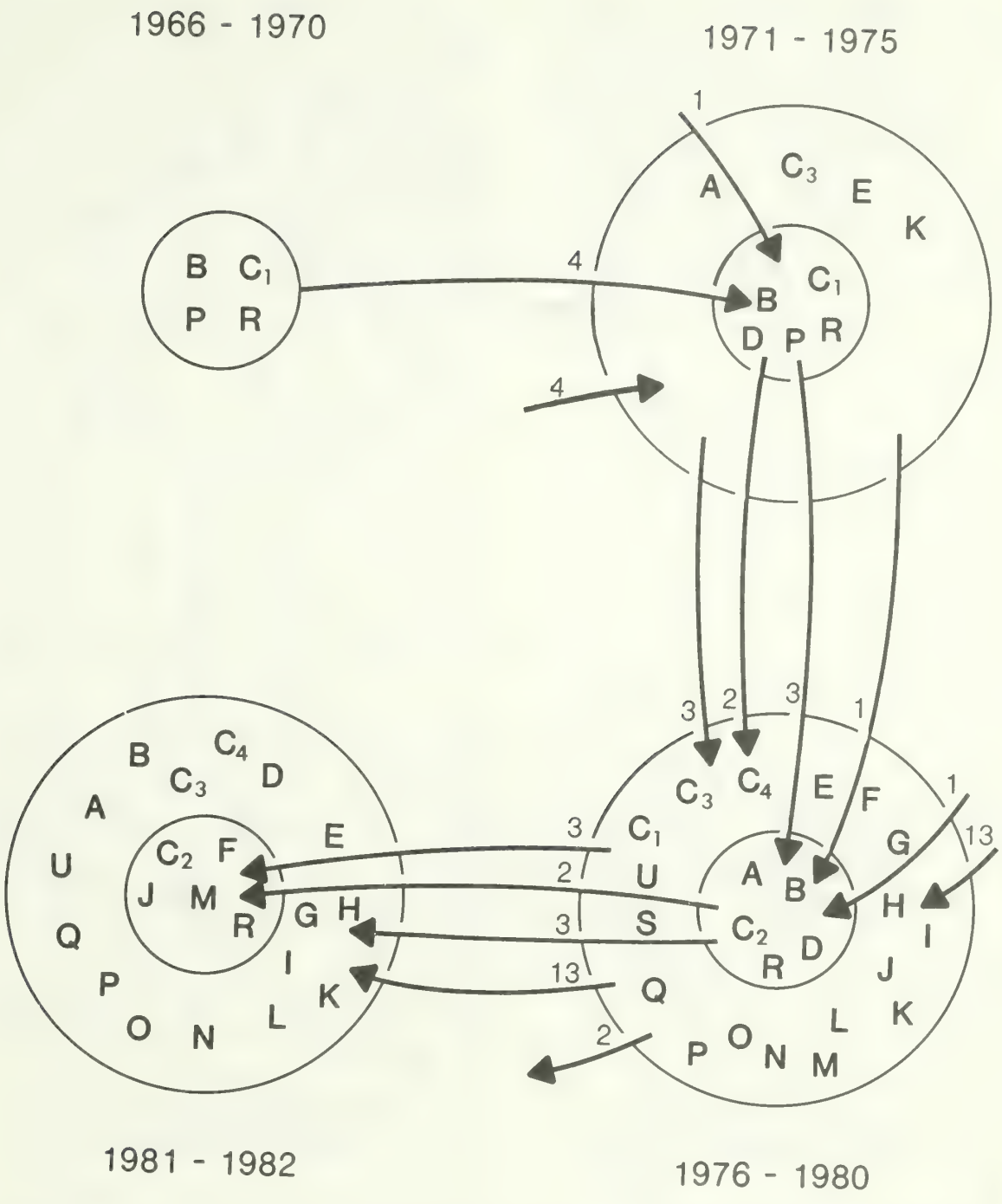


Figure 1.—*Time-participation map for publications of 21 researchers in short-rotation forestry.*

Legend: Letters within in inner circles represent the "IN" researchers or research groups in short-rotation forestry. All researchers publishing in 1966 to 1970 were considered "IN". For the years, 1971-1975 and 1980-1981, "IN" researchers published 5 or more articles, and for the years 1976-1979 published 10 or more articles. Outer circles represent the "FRINGE" researchers, who published less than the 5 or 10 articles. Investigator groups not represented within the inner or outer circles for any time period did not publish any short-rotation forestry articles. Arrows show the number of groups moving between the levels of publications, from one time period to the next.

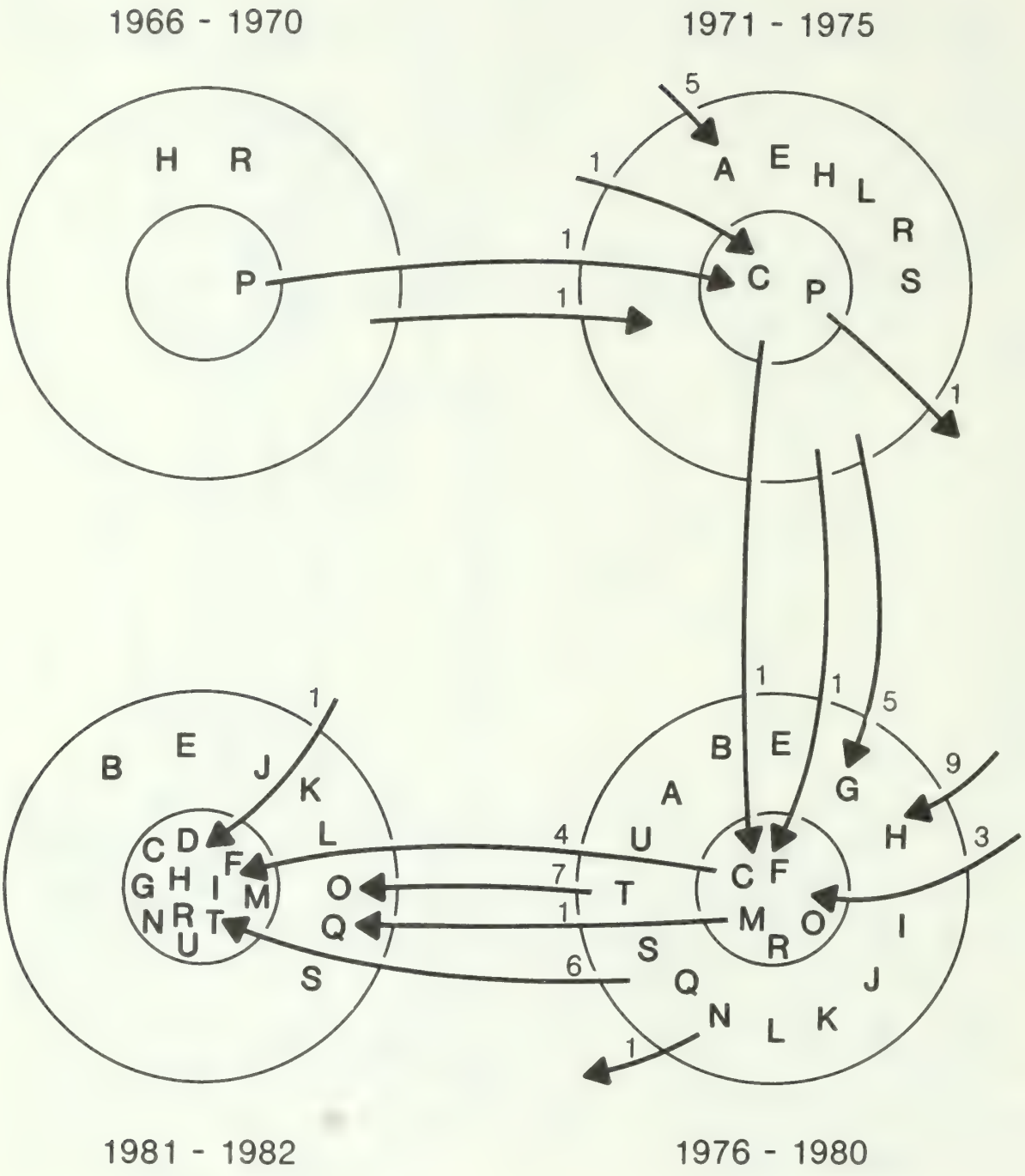


Figure 2.—*Time-participation map for funds received by 21 researchers in short-rotation forestry.*

Legend: Letters within the inner circles represent the "IN" researchers or research groups—those receiving more than $100,000 annually (in years that they received some funds). Outer circles represent the "FRINGE" researchers—those receiving less than $100,000 annually for short-rotation forestry research. Investigator groups not represented within the inner or outer circles for any time period did not receive any funds for short-rotation forestry research during that time period. Arrows show the number of groups moving between the various funding levels, from one time period to the next.

We have drawn several observations about the structure of short-rotation forestry research from these time/participation maps. Figures 1 and 2 suggest that only about half of the "IN" groups are the same for any 5-year period; that is, the groups receiving the most funds did not always publish the most articles. As shown in figure 2, there has been a fairly constant flow of groups into the short-rotation forestry research community, with the greatest increase between the second and third time periods (between 1971-1975 and 1976-1980), coincident with the increased availability of funds. Most of the "recruitment" of groups into the "IN" category was from the "FRINGE" category, and most groups entered the "FRINGE" category from the outside. There are some exceptions: groups A and D entered the "IN" category (for publications) directly from the outside, and groups C, F, M, and O entered the "IN" category (for funds) directly from the outside. Since the cutoff point for being in the "IN" category in terms of funds was $100,000, part of the increase in the number of "IN" groups for funding for the 1981-1982 period can be attributed to five groups that received slightly less than $100,000 annually in 1976-1980 and slightly more than $100,000 in 1981-1982.

The longevity of some researchers and investigator groups in short-rotation forestry extends nearly 20 years, and many individuals have now had nearly 10 years of experience. However, some of the most influential (or most frequently cited) publications were written by scientists who wrote relatively few publications on short-rotation forestry (Fege and Brown 1984). Although most of these scientists probably did not shape the future of short-rotation forestry, their experiences expanded the knowledge of short-rotation forestry concepts within forestry and other research communities.

LESSONS ON RESEARCH EVALUATION METHODS

We consider the application of a range of evaluation measures to the same area of research to be one of the strengths of the entire case study, only part of which is summarized in this paper. By using several different evaluation methods, we were able to confirm many of our observations. For example, conclusions about the organization of short-rotation forestry research were derived from intensive interviews with four groups of researchers, from funding histories, and from analyses of coauthorship patterns. Insights gained from interviews with individual scientists were confirmed by our documentation of the funding and publication patterns.

We consider our familiarity with short-rotation forestry research, our participation in the structure of this research community, and our personal acquaintance with individual researchers to be largely positive aspects of this study. The overall time and effort required to complete the study was much less than it would have been if we had not been familiar with short-rotation forestry, and there was little "start-up" time at the beginning of the study. We tried to keep personal biases and previous experiences with individual scientists and research projects out of the study, although we recognize that perfect objectivity is not possible.

With a view toward applying evaluation methods tested and developed in this case study to other areas of forestry research, we tried several common research evaluation methods developed in other fields of science. These included documenting funds, personal interviewing, surveying active researchers, characterizing publications, and analyzing citation patterns. To our knowledge, few of these have been applied to forestry research, and then only one or two at a time. We are unaware of any other attempts to describe the organization of the research community by coauthorship patterns, to compare several measures of the "productivity" of research groups at the same time, or to examine the participation of research groups within the community over several periods. Describing other areas of forestry research by coauthorship patterns and participation maps should enhance our understanding of the structure of forestry research, and give us further information about how our findings in short-rotation forestry research can be generalized to other areas.

Administrators are commonly interested in evaluating programs from data that are easily and rapidly collected. This has led them to rely almost exclusively on publications. Indeed, the emphasis on publications as the principal measure of "output" became one of the limitations of our study. We made no effort to assess the "usefulness" of individual publications, by either peer judgment or other criteria. With respect to dissemination of research information, we looked only at publications, not at the actual application of the information by users. We had expected that feasibility studies would be a measure of "output," but found that we could not quantify the structure of those studies or the accuracy of production cost data to our satisfaction. There is a need to develop other measures of research productivity and accomplishments that are based on readily available data, as well as to develop methods for using publications to gain more accurate information about research programs.

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VARIABILITY IN RESEARCHER PRODUCTIVITY

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LITERATURE REVIEW

Studies on researcher productivity have shown that there are great differences among individuals in the rate of scientific production. One early study still being cited is Lotka's (1926) analysis of the number of scientific papers produced by physicists. He developed the "inverse square law of scientific productivity," which states:

$$F(n) = \frac{K}{n^2},$$

where n is the number of papers, F(n) is the number of scientists producing n papers, and K is a constant. The distribution for this function is highly skewed, so that for every 100 scientists producing one publication, there are 25 scientists producing two publications, 11 scientists producing three publications, and so on. This leads to the case where three-quarters of the scientists produce only one-quarter of all publications while one-tenth of the scientists produce approximately one-half of all publications (Leikola 1981).

Although later studies on researcher productivity analyzed additional measures of productivity, publications remain one of the more tangible and measurable products of the research process. Pelz and Andrews (1966) collected information on the individual histories and performance of more than 1,300 scientists and engineers in 11 research and development laboratories. They also analyzed laboratory conditions at each location. Performance was measured subjectively (judgments by colleagues in the same laboratory) and objectively (a 5-year count of number of papers in professional journals, patents and patent applications, and unpublished manuscripts). Pelz and Andrews analyzed the relationship between performance and 12 factors: freedom, communication, diversity, dedication, motivation, satisfaction, similarity to colleagues, creativity, age, climate, coordination, and groups. For each relationship the authors offered suggestions as to how research administrators could manage their organizations to enhance productivity.

Data relating the quality of the research published by a scientist to the quantity of research published were presented by Cole and Cole (1968). From the population of university physicists, they drew two samples. First, they sampled 120 physicists, with an over-representation of eminent scientists, to determine (1) number of papers published (used as a measure of publication quantity), (2) number of awards received, (3) number of citations (used as a measure of publication quality), and (4) nationally assessed rank of their department. They then sampled 2,036 physicists to determine the extent to which the work of the scientists in the first sample was known, and the prestige of the awards received by the scientists in the first sample. For physicists, they found a strong correlation between the quantity and quality of the research published. However, they went on to determine that citation counts provided a better measure of quality than number of publications alone.

Cole and Cole proposed two factors to explain the relationship between quantity and quality of research published. First, it is necessary to engage in a large number of research efforts to produce quality research. Second, the scientific reward system operates so that scientists producing quality research are encouraged to continue to produce, while scientists producing research of limited significance are diverted to other areas. When a scientist's work is used by his or her colleagues, that scientist is encouraged to continue doing research; when work is not used, the scientist's efforts decline.

In 1971, Whitley and Frost (1971) summarized and evaluated the progress made in measuring research performance. They approached the problem from a sociological perspective and contended that "...Current problems of measuring performance are not primarily those of devising more sophisticated methodologies, but of arriving at a coherent theoretical framework indicating what is to be measured." After examining various measures of researcher productivity, they concluded: "Although it may be true

that over the entire population of publishing scientists the number of papers produced in the individual's lifetime is related, though not very highly, to the evaluation of his peers...at any one time the mere number of published papers by a researcher is not a valid indicator of the quality of his work."

Cole and Cole (1972) discussed factors affecting scientific productivity when they attacked the Ortega hypothesis. The Ortega hypothesis asserts that without the work of average scientists who make only minor contributions to science, the true breakthroughs by outstanding scientists would be impossible. Cole and Cole find fault in the two basic assumptions of the hypothesis: (1) that the ideas of the average scientist are visible to and used by outstanding scientists, and (2) this minor work is necessary for major breakthroughs. In their analysis, they found that 50 percent of all scientific papers are produced by 10 percent of the scientists. While 15 to 20 percent of the work cited in papers of major breakthroughs is produced by average scientists, Cole and Cole argue that the prevalence of independent multiple discoveries indicates that all scientists are replaceable—although some have more "functional equivalents" than others (Cole and Cole 1972). They suggest that it "...may not be necessary to have 80 percent of the scientific community occupied in producing 15 or 20 percent of the work that is used in significant scientific discoveries, if perhaps only half their number could produce the same work."

Allison and Stewart (1974) picked up on earlier work by Merton (1968) and Cole and Cole (1972) to study accumulative advantage. They stated that because of a variety of social mechanisms, productive scientists are likely to be more productive in the future, while scientists who produce little original work are liable to decline further. The data they collected from chemists, physicists, and mathematicians supported the idea of accumulative advantage. They found that fewer than 6 percent of the publishing scientists typically produced 50 percent of all scientific papers. Allison and Stewart stated that accumulative advantage works for two reasons. First, scientists who are recognized for scientific achievement are motivated by their colleagues' expectations to maintain or increase their recognition. Also, with recognition comes increasing access to resources, which enhances scientific achievement.

In a 1976 study of the Forest Service Research Branch (known as the CRUSK study), Lingwood and Morris (1976) defined productivity as contributions to the field or discipline. They took the view that "there is no contribution inherent *in* new knowledge; there is only contribution *to* some area of the use of knowledge." The authors described the Forest Service as a mission-oriented organization, with the motivation for addressing research problems developing from scientists' curiosity coupled with the needs of some nonscientific individual or group. Based on these observations, they contended that a contribution should be evaluated in terms of its relevance to the solution of real problems. The contribution is shown as progressing through three stages: (1) work product, (2) communicated product, and (3) used product. The contribution could be measured at any of these stages. Ideally, one would like to evaluate a contribution at each stage, looking for concurrence in the evaluations; however, evaluation becomes more difficult as one proceeds through the stages. The authors decided to measure the contribution of a researcher by three standards: (1) opinion of the researcher about his/her contribution, (2) events attended, and (3) written product.

Lingwood and Morris found that their standards correlated "about 0.50 with each other." They compared their ratings with those made by the assistant directors, annual performance reviews, and evaluation panels, and found that their measures correlated "...moderately with AD's ratings, and a bit less with supervisors' and panel data." They also found that there was "...not a very good convergence among the AD, supervisor, and panel data about the researcher's contributions." They concluded: "There is only modest agreement among any of the measures of contribution, and our questionnaire data at least look no worse than the information now collected to evaluate Forest Service researchers."

RESEARCHERS PRODUCTIVITY IN THE FOREST SERVICE

As is apparent even from this limited survey of the literature, there is no consensus on an appropriate measure of researcher productivity. Although extensive research has been done in a few disciplines (notably physics), there is no indication that factors and measures appropriate in one discipline are suitable for another. In terms of forestry research productivity, the literature offers many enticing areas for research but few answers to specific questions.

We have been addressing the problem of understanding and developing measures of forestry researcher productivity at the North Central Forest Experiment Station in Research Work Unit (RWU) NC-4204, Methods for Evaluating Forestry Research. Although approaches for attacking the problem are still being discussed, we began our studies by looking briefly at the number of publications produced by individuals. In the Forest Service, researchers and research managers generally agree that number of publications is the main (and at times, only) criterion for evaluation and promotion

(Lingwood and Morris 1976). Number of publications is also an interesting point of departure in the study of measures of researcher productivity because the numbers produced by individuals vary widely. As Shockley (1957) pointed out in a study of the publication rates of scientists at the Los Alamos Science Laboratory:

> In the study presented here the individuals are presumably specially selected by natural ability and specially trained to accomplish scientific production. Yet the spread in rates is enormously greater than it is for more physical activities.... If the number of scientific publications is used as a measure of productivity, it is found that some individuals create new science at a rate at least 50 times greater than others.

One can obtain an overview of the variability in researcher productivity in the USDA Forest Service by analyzing data in the Research Dissemination Database (RDD). We created the RDD to analyze the outlets used by USDA Forest Service researchers (Forest Service cooperators and employees) in disseminating research results. It contains information describing all research results published in fiscal years 1980 and 1981 (October 1, 1979 through September 30, 1981) by Forest Service researchers at eight regional experiment stations (the Forest Products Laboratory was excluded from this analysis).

To describe the variability in researcher productivity, we eliminated some entries in the RDD that were relevant for assessing outlets used to disseminate research results but cluttered the picture for this analysis. The result was a modified database containing published manuscripts reporting research results by USDA Forest Service employees in fiscal years 1980 and 1981.

During fiscal years 1980 and 1981, 1,561 Forest Service researchers senior-authored 3,621 publications. More than half (53 percent) of the publications were multiauthored (fig. 1). This is comparable to percentages reported in other research disciplines in the U.S. For example, an earlier study showed that in chemistry about 80 percent of the papers are multiauthored, in physics 60 percent, and in biological sciences 40 percent (Zuckerman 1968). However, Leikola (1981) reported that only 25 percent of Finnish forest sciences publications have more than one author.

Twenty Percent of Authors Produce 50 Percent of Publications

In our study, the average annual rate for the 2-year period was 1.2 publications. This average is low because researchers are credited only with the work they senior-author. We do not know if, in the Forest Service, the designation of an individual as a senior author symbolizes any extra credit or responsibility for the work carried out. Zuckerman (1968) identified three patterns of name-ordering on scientific papers: (1) patterns which place all authors on the same plane (such as alphabetical lists), (2) patterns which enhance the visibility of the first author, and (3) patterns which enhance the visibility of an author other than the first author (such as the last author out of order in an alphabetical list). A future study on coauthorship patterns in the Forest Service may help determine the symbolism inherent in the name-ordering of Forest Service research papers. For this study, we'll assume that the individual designated as senior author is primarily responsible for the research, and therefore our publication counts represent a measure of his or her research effort or productivity.

Although the average annual publication rate was 1.2 publications, the range in the number of publications produced by individuals varied widely (fig. 2). A majority of the researchers senior-authored only one publication during the 2-year period. However, 17 individuals senior-authored 10 or more publications. Using this frequency distribution, I grouped the researchers into three classes: low producers, intermediate producers, and high producers (fig. 3). Low producers are researchers who senior-authored one publication. Fifty-two percent of the researchers are in this group, but they accounted for only 22 percent of the publications. Researchers senior-authoring two or three publications were classified as intermediate producers. Twenty-eight percent of the researchers were intermediate producers and they senior-authored 20 percent of the publications. Only 20 percent of the researchers were high producers, but they accounted for 50 percent of the publications. Why such a range in productivity? The RDD

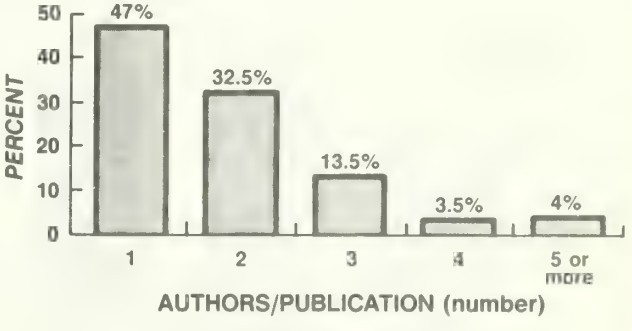


Figure 1.—*Distribution of publications by number of authors per publication, USDA Forest Service, fiscal years 1980 and 1981.*

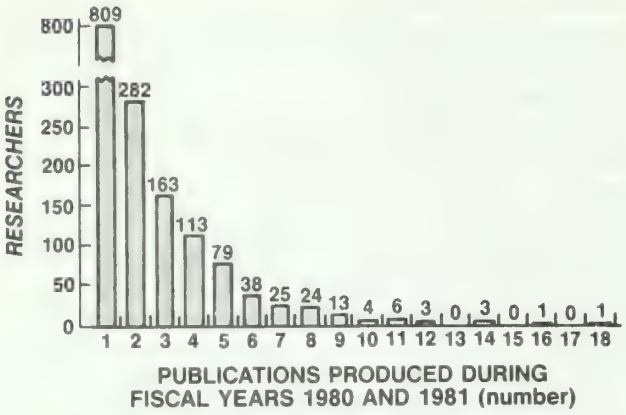


Figure 2.—*Distribution of researchers by the number of publications produced, USDA Forest Service, fiscal years 1980 and 1981.*

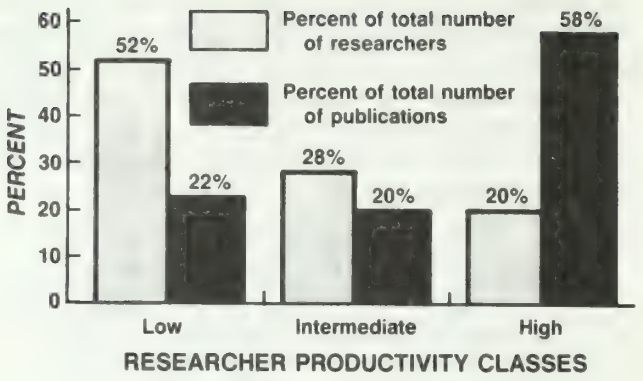


Figure 3.—*Distribution of researchers and number of publications by researcher productivity class, USDA Forest Service, fiscal years 1980 and 1981.*

doesn't provide us with the detailed information we need to fully answer the question, but we can eliminate one or two simple explanations by looking at the publication characteristics of our three researcher classes.

Why Such Variability in Researcher Productivity?

One might hypothesize that high producers had more multi-authored publications than low producers—that one reason high producers are able to produce more is that their research and writing efforts are shared among several individuals. This does not appear to be the case, however; more than half of the publications written by high producers were single-authored (fig. 4). For low producers, 36 percent of the publications had one author, significantly less than the percentage for high producers.

A second explanation of why low producers publish less than high producers might be that low producers are concentrating on quality rather than the quantity of their research output. Research cited above by Cole and Cole (1968) suggests a positive relationship between quality and quantity; however, their findings for physicists may not necessarily apply to forestry researchers. Although our database did not contain any information specifically aimed at measuring the quality of research, it did identify the outlets used by researchers to disseminate research results. The scientific prestige of the various outlets varies. There is some indication that, in the Forest Service, scientific journals are a preferred outlet because the critical peer review used in accepting articles for publication implies scientific credibility (Lingwood and Morris 1976, Simard 1984). Thus, we analyzed the type of outlets used by researchers in our three categories. We categorized the outlets as scientific or nonscientific, based on a system used by Lingwood and Morris (1976) and on guidelines published by the Forest Service for station publication series. The analysis showed there are significant differences between the types of publications used by low, intermediate, and high producers (table 1). This suggests a need for a closer look at the relationship between the quality and quantity of research produced by Forest Service scientists.

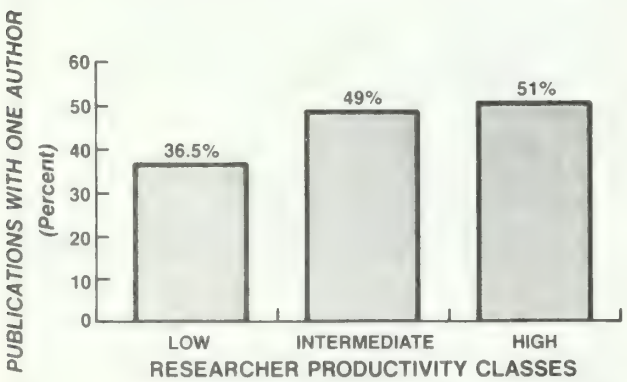


Figure 4.—*Percent of publications with one author by researcher productivity class, USDA Forest Service, fiscal years 1980 and 1981.*

One final question that can be addressed by this information concerns the distribution of low, intermediate, and high producers among research disciplines. Although the distributions are close to what one would expect given the distribution for all researchers, there are some anomalies (table 2). For example, an unusually low percentage of genetics researchers are low producers, while an unusually high percentage of hydrology and wildlife researchers are low producers. Forest inventory and analysis researchers tend to fall into the intermediate category. An unusually large percentage of insect and disease researchers are high producers.

Table 1.--Distribution of publications by type of outlet and researcher productivity class, USDA Forest Service, fiscal years 1980 and 1981

(In percent)

Type of outlet	All researchers	Productivity class		
		Low	Intermediate	High
Scientific				
Forest Service publications	22	20	24	21
Scientific journals	24	25	25	22
Proceedings	23	19	25	22
Books	6	4	5	8
Other	7	14	5	4
Total	82	82	84	79
Nonscientific				
Forest Service publications	6	6	4	8
Nonscientific journals	6	5	7	7
Other	6	7	5	6
Total	18	18	16	21
All types	100	100	100	100
Number of publications	3,621	808	1,053	1,760

Table 2.--Distribution of publications by research discipline and researcher productivity class, USDA Forest Service, fiscal years 1980 and 1981

(In percent)

Research discipline	All researchers	Productivity class		
		Low	Intermediate	High
Silviculture	19	17	18	20
Genetics	4	1	4	5
Hydrology	14	17	12	13
Wildlife	13	17	11	13
Recreation	5	4	5	5
Fire	6	7	7	5
Insects/disease	20	18	17	23
Forest products/engineering	6	6	6	6
Forest inventory and analysis	6	3	9	4
Economics	5	6	8	4
Other	2	4	3	2
All disciplines	100	100	100	100
Number of publications	3,621	808	1,053	1,760

Although the research dissemination database was not created to analyze researcher productivity, we were able to use it in analyzing some characteristics describing the productivity of individual researchers. There is indeed a wide distribution in the number of publications produced by individual researchers, and more study is needed to explain the relationships between quantity and quality of publications and overall productivity.

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SUMMARY: AN EXAMINATION OF THE IMPACTS ASSOCIATED WITH IMPLEMENTATION OF NEW TECHNOLOGY BY A MAJOR NEW INDUSTRY IN A REGION

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In 1969 the Weyerhaeuser Company acquired Dierks Forests, Incorporated. At the time of acquisition, the Dierks holdings in southeastern Oklahoma included 350,000 hectares (877×10^3 ac) of forest land, several hardwood and softwood sawmills, and a medium-density fiberboard plant. The forest land was stocked primarily with mixed stands of oak (*Quercus* spp.) and shortleaf pine (*Pinus echinata*). The silvicultural system which had been applied to the property by Dierks consisted of partial harvesting and natural regeneration.

After acquisition by Weyerhaeuser, major changes were made in primary processing facilities in southeastern Oklahoma. Those included, but were not limited to, a hardboard plant (1970), a particleboard plant (1971), a kraft paperboard plant (1971), and adoption of a softwood plywood plant (1972).

In 1971-1972, Weyerhaeuser introduced extensive loblolly pine (*Pinus taeda*) plantations to the region. The plantation system of silviculture included mechanical harvesting and intensive site preparation for regeneration. This was followed in 1981-1982 by the introduction of first generation, improved loblolly pine developed from seed sources in North Carolina.

The forested part of southeastern Oklahoma is at the northern and western edge of the southern pine region. This location is relatively isolated from the raw material flows common to the interior of the southern pine region.

A second characteristic of southeastern Oklahoma is the dominance of a single forest enterprise, which was first Dierks and after 1969 Weyerhaeuser. This includes ownership of 39 percent of the commercial forest land in the four-county area and the largest of the eight big (annual output of 3×10^6 bd ft or more) sawmills and 17 small (annual output of less than 3×10^3 bd ft) sawmills (Rudis and Jones 1981). The single pulp mill in southeastern Oklahoma is also a Weyerhaeuser mill.

These conditions of relative isolation, single major forest landowner and processor, and a history of major technological implementation make southeastern Oklahoma a unique region in which to examine the economic impact of new technology.

For these reasons, this study has been initiated with the objectives of describing the impact of new forestry technology on the economy of southeastern Oklahoma and developing hypotheses on the economic impact of new technology in forestry for testing.

The study will be conducted in three phases. The first phase will be identification of technologies implemented in the forest products industry in southeastern Oklahoma between 1959 and 1982. The macroeconomic statistics for the region will be examined to determine what correlations can be identified between the implementation of new technology and regional economic activity. The macroeconomic statistics to be examined will include, but not be limited to, gross regional product, nonagricultural employment, personal income, per capita personal income, and unemployment rate. During this phase of the study the Oklahoma State University Office of Business and Economic Research will make a significant contribution in the form of regional data and the results of their previous analyses.

The second phase of the study will concentrate on collection and analysis of cost information for the development, engineering, and implementation phases of selected technologies identified in the first phase.

The third phase will be devoted to hypothesis testing, with the aim of defining relationships between technology identification, development, engineering, and implementation.

The plan is to complete phase one by December 1985 and the remainder of the study by the end of 1988.

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SUMMARY: A TECHNOLOGY ASSESSMENT OF LOBLOLLY PINE[1]

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During the past 70 years, loblolly pine (*Pinus taeda* L.) has become the major commercial forest species of the Southeast. The introduction of numerous new production technologies has bolstered its utilization in the manufacture of paper, plywood, and other forest products, thereby increasing the demand for pine stumpage. At the same time, new technologies for the tree have had significant effects on potential total timber production available from the region. Unfortunately, there has been little research which systematically assesses and projects the impacts of these technologies. Our objective is to perform such an assessment of the technologies that affect the growth of loblolly pine.

Technology assessments of this sort typically feature impacts on many decisionmaking criteria: income, employment, energy, environment, etc. The primary assessment, however, is economic, focusing on the direct and indirect effects on price, quantity, and social welfare arising from adoption of the technology in question. Two commonly used and interrelated approaches for this assessment are the production function approach and the consumer/producer surplus approach. Both of these approaches can provide a focus for the economic analysis of technical change and their use will depend on the ultimate data availability for new technology.

The technologies examined can be divided into two overall categories: Current production technologies (i.e., biological and managerial technologies currently in use, such as tree improvement, regeneration techniques, fertilization, site modification, and insect and disease control), and secondary technologies (i.e., nonbiological, such as machinery and the dissemination of technology or uncertain emerging technologies). Technologies will be discussed separately using similar frameworks of organization to better compare their disparate effects. Direct and indirect effects will be discussed, where possible, within the economic analysis, and other nonmarket effects that address other criteria will be analyzed separately.

[1]*The USDA Forest Service, Southeastern Forest Experiment Station supported this research.*

THE MARKETING OF EVALUATION RESEARCH

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Evaluation research is a line of inquiry and practice that deals with the performance and usage of evaluations. Typical activities in the field include the development of evaluation methods, the study of factors that influence the use (or non-use) of evaluation results, and, at times, the actual carrying out of evaluations, due to the fact that such work is often research in and of itself.

The purpose of this paper is to explore the topic of evaluation research within a marketing context.

Marketing is also a line of inquiry and practice. Amazingly diverse in scope, it centers on the process of exchange between producers and consumers and is directed, primarily, at those producers who would more successfully make such exchanges. Although its origins and primary applications are found in the private sector, its concepts and basic framework for viewing problems are in use in various nonprofit and public sector organizations.

This paper's objective is to demonstrate, mostly by example, how evaluation research can fit into a marketing framework and the possible fruits of doing so. Consider the following imaginary dialogue:

> **Observer** "I just finished reading a review article on quantitative methods for selecting research projects that was in the journal 'IEEE Transactions on Engineering Management'. It said that over the past 15 to 20 years more than 100 such methods have been developed but that few, if any, research organizations have ever used them. How is it that people can continue to develop such useless junk? How do they survive anyway?"
>
> **Marketing Person** "Actually, these people are probably surviving quite well. What they produce is not junk but instead is a type of very high quality evaluation research product. What you failed to notice is that these products are not designed for research organizations but for an entirely different market, the publishers of scholarly journals who put them to very good use."

Marketing, to repeat, is about the making of exchanges and is designed to help the producer do so more effectively. To accomplish this task it adopts a "consumer orientation," which is in effect "a management orientation that holds that the key task of the organization is to determine the needs, wants, and values of a target market and to adapt the organization to delivering the desired satisfactions more effectively and efficiently than its competitors" (Kotler 1976).

The marketing approach sees four critical sets of manageable variables involved in this process once certain basic objectives have been set, strategies developed, and target markets identified and understood. These elements are referred to as the "marketing mix" and are composed of decisions with regard to products themselves, price, promotion (or communication), and distribution. Carried to its fullest extent, a particular marketing mix may be designed for each target market.

The relevance of this topic and this paper in terms of the broader effort of improving evaluation systems for forestry research is quite straightforward, given the fact that a great many workable approaches have existed and been known for evaluating forestry research, yet they have not been used in any systematic evaluation process. Down through the years *ad hoc* evaluations have been carried out and used by various administrators in the Forest Service. However, there has never been an attempt to set up a systematic evaluation system for research within the Forest Service nor in any other forestry research organization.

The point of the present paper is not to argue that evaluation is good or bad or should or should not be used by the Forest Service or other organizations. Rather, the point is that if there is some commitment

to initiating systematic forestry research evaluation in practice, then a marketing approach might well contribute to understanding what is involved, what the evaluation product can be, what "producers" and "consumers" of evaluations gain and give up in an "exchange," and how evaluations can be looked at in a pricing context. This type of perspective will provide useful background understanding which forestry administrators can use to build productive forestry evaluation systems.

EXCHANGE

Marketing is rooted in the concept of exchange, that is, that individuals and organizations gain sustenance through exchanges of tangibles and intangibles with other individuals and organizations. Exchange forms the core phenomenon for study in marketing (Bagozzi 1975).

Exchangeability is the capability of a thing (tangible or intangible) being traded for some other thing, for a price (Fine 1981). Ruling out coercion and the like, "the gist of the exchange notion is that producers and consumers will exchange product for payment if and only if both expect their net satisfaction to be higher after the transaction has been consummated" (Enis 1982).

Exchanges generally take on one of three forms (Bagozzi 1975). A "restricted exchange" involves two-party reciprocal relationships, each party receiving something of value from the other. A "generalized exchange" involves at least three parties, in which the parties do not benefit from each other directly but only indirectly. This might be represented by: A gives to B, B gives to C, and then C gives to A. The third type, a "complex exchange," involves a system of relationships among at least three parties, each of which is involved in at least one direct exchange, while the entire system is organized by a web of interconnecting relationships.

Individuals and organizations that do evaluation research work are involved in exchange relationships with other individuals and organizations. These exchanges involve a mix of tangible and intangible things flowing between those involved.

Figure 1 depicts the formal products and services, and the relationships common to evaluation research. It could represent, for example, a university professor (professors have done much of the evaluation research work in the areas of agriculture, industry, and forestry).

Professor X in this example has received a grant from a research organization to do a study on, say, the economic returns to a particular line of research. Professor X also receives a title, office, and support from his employer, the university. With the grant Professor X pays a supplier, perhaps a graduate student, in exchange for his services (help) on the study. Together, Professor X and the graduate student complete the study. They send it, in report form, off to the research organization to complete that exchange. Professor X, with or without the graduate student, may prepare one or more research manuscripts based on the study and submit them to various publishers, such as SAGE, which puts out the journal "Evaluation Research". Found satisfactory, the manuscripts are published, completing this exchange. Later, in at least partial return for his rank, office and the like, Professor X forwards evidence of his publication to his employer, the university.

In addition to identifying common reciprocal relationships in evaluation research work, figure 1 brings out various other aspects of the exchange process. The evaluation researcher functions in several distinct markets. Each market, in exchange for the evaluation researcher's offerings, pays a price but that price differs considerably from market to market. All markets, however, part with scarce items. In exchange for these "payments" the evaluation researcher has offered the results of his work, but in a somewhat different form, to each market.

PRODUCTS

Marketing is about the exchange of things between producers and consumers. Generically, all such things are considered as products, that is, anything having the ability to satisfy human needs and wants (Fine 1981). More specifically, organizations can try to market up to six types of products (Kotler 1972): goods, services, organizations, persons, places, and ideas.

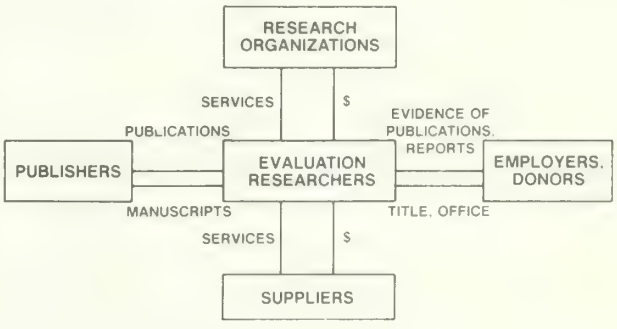


Figure 1.—*Common exchange patterns in evaluation research.*

Due to its consumer orientation, however, the marketing approach requires producers to attempt to define products from the consumer's point of view. To do so leads the producers to recognize, and work with, the notions that:

1. Consumers receive psychological as well as physical benefits in making exchanges (Kinnear and Bernhardt 1983).

2. These benefits may be enhanced or diminished, depending on the consumer's evaluation of the product as part of a total package which often includes features that are not strictly necessary to enjoy the product itself.

A product's physical attributes motivate what Bagozzi (1975) calls "utilitarian exchanges," those stimulated by the consumer's anticipated use of the tangible characteristics associated with the product. In contrast, "symbolic exchanges" involve the transfer of psychological, social, or other intangible entities. This concept "...means that sellers of goods are engaged whether willfully or not, in selling symbols, as well as practical merchandise..." because "...people buy things not only for what they can do, but also for what they mean" (Levy 1959 as quoted by Bagozzi 1975). Exchanges commonly have both utilitarian and symbolic aspects.

In marketing terminology, the producer's offering is referred to as the "formal product." The satisfaction that consumers experience from the formal product is termed the "core product." It is also meaningful to delineate the "augmented product"—the total package of product features made available to the consumer—which might include, for example, the comfort of the seats in a concert hall in addition to the symphony performed. The satisfaction received by the consumer from the augmented product is sometimes referred to as the "peripheral product" (Laczniak 1980).

Evaluation researchers produce various formal products ranging from goods to services and, perhaps, even to ideas to the extent that they seek to advance the concept of evaluation itself. A few examples of such products are given in table 1.

Table 1.--Examples of evaluation research products

General example	Specific example
PRODUCT--GOODS	
Scholarly work	An article in the Journal of Forest Science titled "Economic Impacts of Structural Particleboard Research" (Bengston 1984)
Evaluation technology	A method for measuring the benefits of drought research (Leholm et al. 1981)
PRODUCT--SERVICES	
Education	A university course titled "Sociology 5821: Evaluation Research," which is to "prepare students to conduct actual evaluation research" (Office of Admissions and Records 1980)
Consulting	A multidimensional R&D benefit/cost model developed for the U.S. Dept. of Energy (Silverman 1981)
PRODUCT--IDEAS	
Concept of need	"... business firms and government agencies badly need better measures of return from R&D" (Mansfield 1965)

From a marketing standpoint these formal products become core products when viewed through the consumer's eyes. One set of consumers, figure 1, is composed of research organizations.

For public forestry research organizations, evaluations tend to be used for two general purposes (Gregersen *et al.* 1983): (1) Program planning and budgeting and (2) justification of past research (often in support of new proposals). Table 2 explains these uses in greater detail. It also shows that the final consumers of the evaluation product may or may not be those who produce or commission the product.

Disregarding, for the moment, who the final consumer is for the product, it can be said that all the formal products of evaluation research aimed at the research organization are information products of one sort or another. The information contained in evaluation reports or generated by evaluation methods are a major source, but not the only source, of the satisfaction that the consumer derives from the exchange. In Bagozzi's terms the consumer's anticipated use of this information stimulates the "utilitarian" aspects of the exchange. Appropriately, Eisgruber (1978) comments:

> Data are not information. The demand for data is generated by the need to make decisions on problems, but decision makers rarely use raw data. Rather, there are intervening acts of interpretation, through statistical and economic analysis, policy staff and political evaluation, etc., which transforms data into information by placing them in a specific problem context to give meaning to a particular decision.

In an economic sense, this decision-based demand for information stems from the uncertainty which surrounds decisions. Uncertainty, as Hirshleifer (1973) defines the term, "...is summarized by the dispersion of individuals' subjective probability (or belief) over possible states of the world." He says, further, that information "...consists of events tending to change these probability distributions...it is changes in belief distributions—a process, not a condition—that constitutes here the essence of information." But Nicholson (1972) says, "First, the individual is concerned with the utilities of uncertain events." In effect, then, it is the interaction of two factors, uncertainty and utility, that stimulates the demand for information that Eisgruber referred to and that gives potential value to evaluation information, which here is an enhancement of the expected value of the decision to be made.

From the consumer's standpoint, then, one form of utility received or anticipated as a result of the exchange with the evaluation researcher is a reduction in uncertainty. But, as the marketing approach indicates, the core product may have psychological, social, or other more or less "symbolic" values as well.

Table 2.--Evaluation users and uses in a public research organization[1/]

Evaluation producers and users	Major Purpose of Evaluation	
	Program planning and budgeting	Justify past research and support new proposals
Legislators and executive	Used to evaluate proposals and supporting documentation, make specific allocations of budget, confirm intentions	Used to explain and support budget and policy decisions to electorate--rare in forestry research matters
Forestry research administrators	Used to facilitate discretionary budget and hiring decisions, enhance program management and output monitoring, check for policy compliance	Used to validate past research efforts to legislators and executive, help substantiate funding proposals
Researchers	Used to facilitate specific project funding allocations, design new projects, explore feasibility	Used to account for completed projects, provide supporting information for new projects

1/ Gregersen et al. 1983, p. 74.

The nature of the symbolic utility of evaluation research to the research organization can be speculated upon. Certainly the fact that industrial groups have funded a great deal of evaluation research, the results of which they have been unable to use (cf. Clarke 1974), might be taken to mean that they receive some other value from the endeavor. According to Rettig *et al.* (1975), one of the three contributions of research and development to the firm is that it provides the firm with an image of progressivity. It seems at least possible that evaluation research may have similar symbolic value to the research organization. According to Mansfield (1981), in some industrial laboratories quantitative evaluation models "...are little more than window dressing for professional hunches and intra-company politics."

One purpose of looking at the product from the consumer's viewpoint is, of course, so that the producer may better perform the task of product management: the planning, organization, implementation, and control of products made available to consumers. More specifically, it involves activities such as setting product goals and objectives, determining the benefits or utility that product users derive, evaluating product performance, modifying existing products, and developing new product offerings (Laczniak 1980).

The notion of the augmented product—that is, the total package of product features made available to the consumer—is a facet of product management. The association of a prestigious personality with an evaluation, for example, may have little influence on the content of the evaluation's results. Nevertheless, in the eyes of the consumer—for example, a Congressional committee—this association may enhance the evaluation's acceptance by helping to establish its objectivity. A 1976 report from a House subcommittee, for example, said, "The most significant factor in evaluating a benefit-cost study is the name of the sponsor" (Gregersen *et al.* 1983). Table 3 summarizes the product concepts discussed.

PRICE

For a marketing transaction to take place, something must be paid out by the purchaser (Fine 1981). The purchaser/consumer need not necessarily pay the producer directly, as the earlier discussion on the three general forms of exchange showed. Nevertheless, the consumer must part with something of value and, eventually, the producer must receive something of value—sometimes directly from the purchaser and sometimes indirectly as a result of the consumer's actions.

Private sector marketers typically have concentrated on the money aspects of price but, as Fine states, "If consumers do indeed perceive themselves as expending resources beyond money when they make purchases, it becomes important for purveyors to take into account these 'things' given up in exchange" (1981). To do so he develops a price construct with two components. One is the price paid in cash, the other is a nonmonetary or intrinsic component extending beyond money, which he calls social prices. In equation form the construct becomes:

$$P = p_m + \sum_{i=1}^{n} p_i$$

Table 3.--A typology of the evaluation product

	A narrow conception	A broad conception
From producer's standpoint	The formal product --the evaluation product itself (that is, the study, method etc.)	The augmented product-- all the attributes connected with the evaluation product (that is, the association of outside experts, etc.)
From consumer's standpoint	The core product-- the satisfaction consumers experience from the formal product (that is, reduction of uncertainty, image of progressivity, etc.)	The peripheral product-- the satisfaction consumers experience from the augmented product (for example, greater confidence due to objectivity of outside experts involvement in product development)

Source: Adapted from Laczniak 1980.

where:

P = total price
p_m = monetary price
p_i = a set of "social" or nonmonetary prices.

It would be difficult to apply this model, yet its concepts are useful for illustrating how consumers respond to a price construct greater than money alone. Consider an example given by Kinnear and Bernhardt (1983), which contrasts a gallon of milk for sale at $1.75 at a typical supermarket with the same item for sale at $2.05 at a 7-11 type store. Milk purchasers at 7-11 are compensated for paying more money by the convenience, such as being able to park close to the door and to avoid long waits in line at the checkout counter. At the supermarket, the situation is reversed.

The nonmonetary price in this example is, of course, the consumer's *time* which is one of four categories of resources that Fine suggests as being given up (beyond money) in exchange for product offerings. The remaining three are effort, lifestyle, and psyche.

As Fine says, expending one's *effort* in exchange for a product is merely bartering one's services in that exchange. Other things being equal, the difference between time, as a cost, and effort, would seem to be the negative or positive utilities associated with the effort—fatigue, for example—or the pleasure of doing something by one's own hands (or head).

Modification of one's *lifestyle* is also a price paid out in many forms of exchange. As Fine says, "While some may thrive on diversity and change, most individuals look upon the prospect of disruption of the status quo with at least some trepidation and this is true whether the anticipated change is for the better or for the worse." Another part of the price of exchange often amounts to a forfeit of self-esteem, identity, self-assertion, privacy, control, freedom from fear or risk, or other such losses affecting a person's peace of mind; they are thus grouped under the heading of *psyche*.

One final aspect of this price concept is that with the exception of money, each of the four categories of resources listed (time, effort, lifestyle, and psyche) might be either part of the cost of the exchange or a benefit-generating attribute of the product. Time and effort savings are often a product's major benefit, for example.

The acquisition and use of evaluation research products obviously costs the consumer. As figure 1 illustrated, these costs can take on various forms in the exchange relationships between Professor X and his publisher, the research organization, and his employer the university. From his publisher Professor X received no money; in fact, he may even have paid a page charge to the publisher. What he got from the publisher was a formal recognition of the validity and importance of his work—an intangible that he will trade with others like his employer later on.

The costs paid by the publisher on the other hand, in addition to the money involved in the actual journal printing, may involve the expenditure of considerable time and effort to judge the worth of the Professor's manuscript. Of course, it is also possible that manuscript reviewers enjoy such choices; yet, those who sit in judgment in such situations risk the loss of professional esteem should they validate what later proves to be poor work.

In addition to paying money to acquire an evaluation research product, research organizations are often faced with additional money costs in using it. One of these costs is more or less a "translation" cost. In discussing the use of research evaluations done by "experts," Fishel (1981) says, with reference to their products: "In most cases, this usually consists of a partial analysis of the total decision situation. Someone else then must further analyze the contribution of the experts...." Mansfield (1981) cites an estimate for setting up an evaluation model developed by Honeywell at about $250,000, and the annual cost of maintaining it at about $50,000.

An additional monetary aspect of the usage of evaluation research products is the distribution of the costs, and benefits, that may arise as a result of implementing an evaluation's findings, a point which Wildavsky (1978) has made.

As has been mentioned frequently here, research organizations have generally declined to adopt and put into everyday use the many formal, quantitative evaluation methods that have been developed, supposedly, for them. Most explanations of this lack of application cite technical problems with the methods—that is, the products don't work. While this may well be a major cause, there may be cost/price problems as well that go beyond the money involved.

The dominant forms of research evaluation within research organizations are managerial expertise and peer group reviews. This, Bozeman (1979) argues, is an outgrowth of "straight arrow" science, which is more or less the textbook model of science. Because most of the science administrators are former scientists, the clients and/or fundees are scientists, the outside advisors are scientists, and scientists have been instrumental in establishing and structuring the organization, the values, norms and interests of the scientific community are pervasive

and often influence nonscientists who may be involved.

Straight-arrow science, Bozeman says, purports that the work of highly specialized professionals can only be evaluated by other highly specialized professionals. It also encompasses the norm of "autonomy" which is almost universally accepted in the scientific community.

The problem here is that straight-arrow science spills over into the arena of science policy and often means that only internal, science-based criteria are employed in research assessment.

Adopting evaluation methods that include criteria other than theoretical and technical considerations may then imply to the scientist-dominated research organization significant costs that might be described in terms of "lifestyle" and "psyche" costs.

DISCUSSION

This paper has sought to show how evaluation research can be looked at within a marketing context. It demonstrates that evaluation researchers can be conceived of as producers/marketers who design and offer various sorts of products to various markets. The people who accept the evaluation researcher's wares anticipate various kinds of benefits from the products and pay various kinds of prices to acquire and use them.

Marketing is more than a framework, although its orderly conceptualization of the factors and forces involved in exchange relationships is one of its strengths. It also provides direction for the gathering of information and a means to make positive use of information in terms of product, price, promotion, and distribution decisions.

Evaluation researchers, as conceived of here, apparently do not have much in the way of marketing problems in their exchange relationships with markets like journal publishers and their employers. They do, however, have problems with another major market, research organizations. It could also be the case that research organizations, or certain elements within them, have problems with the marketing programs of evaluation researchers.

The marketing approach differs from what might be called "marketing by default" in that it makes product price, distribution, and promotional decisions by design and with forethought. One element of forethought entails the definition of the markets to be sought and at times a further segmentation of these markets into distinct groupings. Market definition is the task of choosing the arena in which to compete and the process through which demand segments within a market are defined and described and their potential as market targets assessed (Fennel 1982).

The research organization may be thought of as a market having distinct demand elements (segments) within it. One way to segment this market might be on the basis of the "roles" played by evaluation information that Fishel (1981) lists in his assessment of evaluation research related to agriculture (table 4). Evaluation researchers, therefore, perhaps have implicitly targeted Fishel's education role market segment at least in major part.

Gregersen *et al.* (1983) would have called "education" by another term, "justification." Gregersen's other major use of evaluation, program planning and budgeting, could be the market segment to which much of the often-mentioned quantitative evaluation methods were aimed. It seems clear, however, that the characteristics of this segment have not been well defined and described as a marketing approach would dictate. Part of the problem is that evaluation researchers tend to view the consumer in a manner quite different from the marketer. Fine (1981) explains:

> Marketers assume limited rationality in individuals. They are aware that consumer choice decisions are complicated phenomenon—the complex man theory—and are based on emotion as much as upon reason. In addition to reason decision making rests upon phenomena such as—perceptions, values, attitudes, group influence and personality. Marketers further believe that utility satisfaction is not ordinarily maximized but merely "satisfied," that is, satisfied with something "good enough" rather than optimality. Thus marketers investigate the properties inherent in product offerings that are capable of providing utility and then set out to provide those products most likely to satisfy.

There is ample evidence to demonstrate how evaluation researchers adopt a decidedly nonmarketing view of their potential consumers in the planning and budgeting segment. Souder (1978) does this nicely as he contrasts the "real world" with an idealized view of decisionmaking commonly assumed by the evaluation researchers (table 5).

Table 4.--Fishel's view on the success of research evaluation information in fulfilling its base roles[1/]

Role	Fishel's assessment
Education[2/]	In this role, "... we have probably achieved our singular success. The studies to date and resulting information have been good and they have been useful."
Policymaking	In this role, "... I would submit that R&E evaluation information has had little direct effect ... for whatever reasons, economic returns information is not considered useful or adequate relative to other information."
Resource allocation	"... evaluation information has not entered directly in the consideration of program or budget development decisions with which I have been associated at the federal or state levels."

1/ Fishel (1981).
2/ "primary function of making us more knowledgeable about the R&E environment ... foundation or base knowledge"

CONCLUSION

To reiterate, exchanges take place when each party involved in that exchange anticipates that his net satisfaction will be increased as a result of the exchange.

One party to the exchange process for certain lines of evaluation research products is the individuals involved in research planning and budgeting. These individuals could be coerced into making use of evaluation methods other than the manager expertise and peer group review approaches, but then there would be no exchange and probably little value resulting. To culminate free exchanges with this group requires the development of products that will be perceived as generators of net satisfaction. It is possible that some of the products that have been offered would work quite well if they were augmented to include attributes such as training programs and "after sale" consulting services.

Whatever the case, it is necessary to do some market segmentation research prior to putting marketing tools to work here. We need to know a great deal more about the consumers in question.

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Table 5.--Two views of research decisionmaking

The viewpoint that management science models seem to take
1. A single decisionmaker, in a well-behaved environment.
2. Perfect information about candidate projects and their characteristics; outputs, values and risks of candidates known and quantifiable.
3. Well-known, invariant goals.
4. Decisionmaking information is concentrated in the hands of the decisionmaker, so that he has all the information he needs to make a decision.
5. The decisionmaker is able to articulate all consequences.
6. Candidate projects are viewed as independent entities, to be individually evaluated on their own merits.
7. A single objective, usually expected value maximization or profit maximimization, is assumed and the constraints are primarily budgetary in nature.
8. The best portfolio of projects is determined on economic grounds.
9. The budget is "optimized" in a single decision.
10. One single, economically "best," overall decision is sought.
The real world environment
1. Many decisionmakers and many decision influencers, in a dynamic organizational environment.
2. Imperfect information about candidate projects and their characteristics; outputs and values of projects are difficult to specify; uncertainty accompanies all estimates.
3. Ever-changing, fuzzy goals.
4. Decisionmaking information is highly splintered and scattered piecemeal throughout the organization, with no one part of the organization having all the information needed for decisionmaking.
5. The decisionmaker is often unable or unwilling to state outcomes and consequences.
6. Candidate projects are often technically and economically interdependent.
7. There are sometimes conflicting multiple objectives and multiple constraints, and these are often noneconomic in nature.
8. Satisfactory portfolios may possess many noneconomic characteristics.
9. An iterative, recycling budget determination process is used.
10. What seems to be the "best" decision for the total organization may not be seen as best by each department or party, so that many conflicts may arise.

Source: Souder 1978.

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SUMMARY: ESTIMATING PRODUCTIVITY CHANGES DUE TO TIMBER MANAGEMENT RESEARCH IN THE LAKE STATES

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A substantial portion of the North Central Forest Experiment Station's program consists of timber management research. The effects of this research on the productivity (either potential or realized) of the Lake States forests have not been estimated.

The question of improved productivity resulting from research-generated knowledge hinges on two factors. First is the per-acre increase in growth and yield of the researched timber type and stand condition due to the new information. An example could be an increase in growth and yield due to a new thinning schedule. In the Lake States, we have recently learned that it is feasible to grow red pine at higher basal areas. The effect of this new information can be measured and the benefits estimated.

The second factor is the number of acres on which improved management is applied. Factors affecting the rate of diffusion are important determinants of the benefits to research. It can be difficult to correctly attribute the benefits from applied knowledge to the research or to technology transfer efforts.

Of course, costs of the relevant factors in both research and extension or technology transfer efforts must be accounted for.

Two approaches to estimating some of the impacts from, and returns to, timber management research in the Lake States are being considered. Not all effects can be estimated, but these studies will provide a start.

The first study will take advantage of a technology transfer effort in Itasca County. The North Central Station and the County will be implementing the latest research recommendations in timber, watershed, and wildlife management. Differences in per-acre productivity will be compared in a before-and-after format on the affected acres. Comparisons will also be made with neighboring management units. Historical records should allow us to identify the changes.

A second study under consideration is to look back at the knowledge accumulated over the past several decades in timber management research. The scheme will be to select timber types and stand conditions on which research has been done and compare recommended (or practiced) management before and after new knowledge was gained. In effect, we will be asking, "How would this stand have been managed if we had 1950 knowledge versus 1984 knowledge?" The management recommendations can be run through a computer model such as STEMS, and the difference quantified.

SUPPLY FUNCTIONS AND SOCIAL RETURNS TO RESEARCH

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Two major approaches are currently used by economists to study the economic impact of new process research which raises the productivity of factors of production (for reviews, see Davis 1981, and Norton and Davis 1981). One approach uses supply and demand curves to estimate increases in consumer and producer surplus or, alternatively, to measure net economic benefit, which then allows the calculation of an internal rate of return on research and development (R&D) investment and benefit/cost ratios. I will refer to this type of study as a supply function approach.

The other type of study involves the estimation of a production function where research efforts or expenditures enter as a factor of production. This approach is useful in examining the impact of research in terms of its marginal productivity and may be used to determine the value of the marginal product of research or a marginal internal rate of return on research investment. This type of study is often referred to as a production function approach.

The production function approach is currently favored as being more representative of returns to research, not because it allows the estimation to proceed in concentrated industries where a supply curve may not be defined, but due to the manner in which the supply function approach has been applied. Griliches (1979) writes that supply function studies are "very data- and time-expensive and are always subject to attack as not being representative since they tend to concentrate on prominent and successful innovations and fields."

In fact, Griliches' criticism is very true of supply function studies. This stems from the fact that the supply function approach began as (and continues to be) a residual approach. There has been no effort to pin down unbiased estimates of the impact of R&D on the supply curve. All observed welfare improvements have been attributed to R&D. (For an extensive critique, see Seldon 1983.)

To make the problems more obvious, consider how such a study might proceed. We begin with observations of price and quantity at two points in time—once before and once after a particular innovation occurs. That is, all we know so far are points A and B in figure 1. The next step is to obtain an estimate of the price elasticity of supply. This is usually obtained from other studies which do not take R&D into consideration. We then construct supply curves through the two points. In figure 1, supply curve S_A is the presumed supply curve before the innovation, while supply curve S_B is presumed after the innovation. A demand curve D is then drawn through the two points. This graph is then used to calculate changes in consumer and producer surplus and net economic benefits. All observed societal improvement is then credited to R&D.

This procedure introduces various biases into the estimates. For instance, the rightward shift of the supply curve may have been caused in part by a fall in the real wage. Then the shift attributed to R&D is overestimated. Alternatively, perhaps the real wage increased. Then the impact of R&D is underestimated.

The elasticities of supply and demand may also cause problems. If R&D is indeed important but has not been used as an exogenous variable in the estimation of the supply equation then the elasticity of

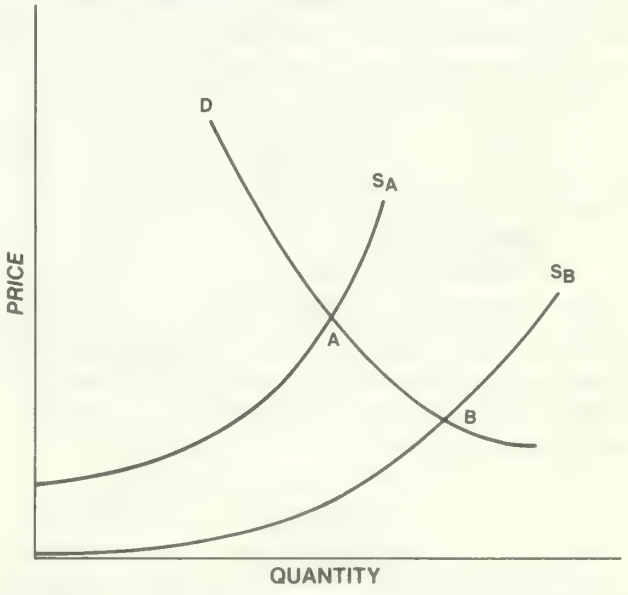


Figure 1.—*The conventional supply function approach.*

supply is likely to be biased, although the direction is uncertain. In the application described above, the demand elasticity is almost certainly biased, since there is no reason to presume the demand curve has not shifted.

Another troublesome aspect of this type of study is determining the costs of research which allow a particular breakthrough. Any innovation is accomplished by building upon past achievements. Therefore, questions arise: How far into the past should we count costs? And how can we account for all recent costs that allowed an innovation? Surely there are spillovers such that one type of research aimed at a particular product aids other research directed at the same product.

After such decisions are made, benefit/cost ratios and internal rates of return may be calculated in the usual way. But another problem arises. How long will benefits last? It is customary to obtain limits on the returns to research by alternatively assuming benefits last only one period or that they will last forever.

PROCEDURE

An alternative to this residual supply function approach is a nonresidual approach which is a straightforward extension of the production function approach (this is fully developed in Seldon 1985). The production function approach was originally a residual approach, but has evolved into studies which consider R&D to be an integral part of the production process (see, e.g. Griliches 1964). Since the main concern of such studies is the impacts of R&D, issues concerning the functional form of the production function are largely ignored as not being very crucial or interesting, and the easily handled Cobb-Douglas function is commonly used (Griliches 1979).

Thus we begin with an equation of the form

$$Q_t = AL_t^c K_t^f T_t \ ,$$

where Q_t is quantity produced,
L_t is labor input,
K_t is capital services,
and T_t is an index of technology,

all at time t. Technology is a function of all past R&D effort, and may be specified as a linear function, but in some ways is easier to handle if we assume a multiplicative version:

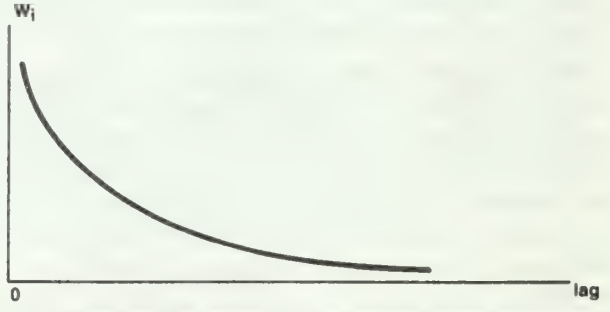
$$T = \prod_{i=0}^{\infty} R_{t-1}^{d_i} \ .$$

It simplifies the analysis to assume some form of distributed lag on the technology function. The form of the distributed lag depends upon reasonable assumptions made in light of the particular industry. We might expect that the effect of R&D "long ago" is less important for production today than more recent R&D, since the effects of R&D depreciate in a sense—perhaps because producers forget, but more importantly because new innovations displace older innovations when they both perform relatively similar functions. On the other hand, when innovations require large capital investments, we might expect that all producers will not use new processes immediately, but rather will wait until old equipment is to be replaced. The lag weights for two cases are illustrated in figure 2.

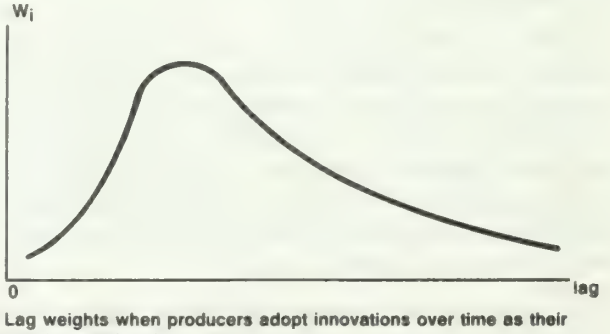
In the agricultural literature especially, it is typical to assume the form of figure 2A, which is the familiar Koyck lag. Say, for instance, that it takes 2 years for producers to evaluate innovations and then to adopt them, but all producers do so simultaneously. We assume that all firms maximize profit over a convex profit function so that industry profit is maximized (Debreu 1959). The functional form of the industry profit function is, in the Cobb-Douglas case,

$$\Pi = P_t AL_t^c K_t^f R_{t-2}^d R_{t-3}^{Ld} R_{t-4}^{L^2 d} \times \ldots - W_t L_t - I_t K_t$$

where W_t and I_t are the real wage and real cost of capital at time t. Maximizing this function with respect to L_t and K_t and solving for the optimal quan-



A. Lag weights when all producers use innovations almost immediately.



B. Lag weights when producers adopt innovations over time as their old equipment deteriorates.

Figure 2.—*Distributed R&D lags.*

tities of labor and capital services allows us to reformulate Π in terms of wages and cost of capital. Rearranging terms then gives a supply function which is linear in the logs. The research term falls through into the supply equation as an exogenous term, since any change in research effort today will not impact production until (in this case) 2 years into the future.

Using this derived supply equation and performing the Koyck transformation (Kmenta 1971) gives

$$q_t = (1 - L)b_o + b_1p_t - Lb_1p_{t-1} - b_2w_t + Lb_2w_{t-1}$$

$$- b_3i_t + Lb_3i_{t-1} + dr_{t-2} + Lq_{t-1} \ ;$$

where lower case letters indicate logs and the b_i's are nonlinear combinations of the parameters from the profit function. We can then estimate this supply equation simultaneously with a demand function, e.g.,

$$q_t = a_o - a_1p_t + a_2y_t \ ,$$

where y_t is an exogenous demand shifter.

In this manner, we can estimate the average impact of R&D on the supply equation. We can proceed in the following manner: For each period in the time series we know price and quantity and have presumably unbiased estimates of the elasticities of supply and demand (b_1 and a_1, respectively). We estimate the impact of today's R&D on supply curves in the future, *ceteris paribus*. That is, the demand curve remains the same and the supply curve shifts due to R&D *only*. In our example, the initial impact is 2 years in the future; hence, assuming the initial supply curve S_t in figure 3, we obtain the supply curve S_{t+2}. This gives us the economic impact of today's R&D that will be obtained 2 years hence, *ceteris paribus*. We then do the same for the expected supply curve 3 years hence, given the supply curve and R&D today—S_{t+3} in figure 3—and obtain the returns to research due to R&D today. We continue to do this until the benefits are small enough to be ignored. Note that this procedure is similar to the estimation of an exogenous shock in any well-balanced system. We can then obtain the total discounted benefits for research at time t as

$$B_t = \sum_{i=2}^{N} \frac{1}{(1 + \rho)^i} B_i$$

where ρ is the appropriate social discount rate, B_i is the benefits for period i years hence due to research today, and N is the time at which returns become negligible. Net economic benefit is found by subtracting the costs of research from B_t, and the benefit/cost ratio is found as usual.

We can do this for each period in our sample and then, discounting the discounted terms, we can estimate the return to the research program over the period of our sample. We may then solve for the internal rate of return to research.

RESULTS

This methodology has been applied to determine the productivity of public research in the softwood plywood (SWPW) industry (for complete details see Seldon 1985). The actual model is similar to the one described above—it has a Cobb-Douglas form, with a Koyck lag identical to the one already described. In terms of the parameters necessary for the estimation of returns to research, we estimated a demand elasticity (a_1 above) of 2.665 in absolute value, a supply elasticity of 0.5011, and L and d of the supply equation as 0.8679 and 0.0219, respectively. Costs were estimated from records of government scientists' effort in attainment reports maintained by the Forest Products Laboratory (FPL) in Madison, Wisconsin. To capture private expenditures induced by government expenditures, we multiplied the total government expenditures by the number of plants times 0.26. This factor was estimated in the case of the powered back up roll and is likely to be high relative to other innovations during the period of our study (Seldon 1985). We should, therefore, be overestimating costs and underestimating net benefits.

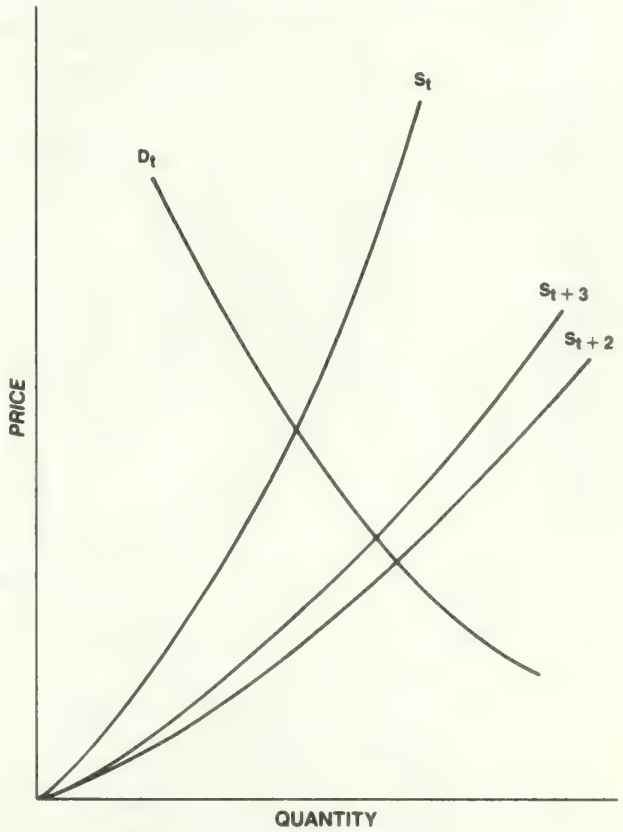


Figure 3.—*Applying the nonresidual supply function approach.*

We solved for the present value of the program for the years 1950 through 1980 assuming social discount rates of 4, 7, and 10 percent, which are the rates used for project evaluation by the U.S. Forest Service, the Water Resources Council, and the Office of Management and Budget, respectively. We then solved for the internal rate of return.

Before giving our results, we should note that intermediate results give an average value of the marginal product of research that matches rather well with those found by Griliches (1964) for aggregate agricultural research and Peterson (1967) for poultry research. In 1967 dollars, we found a first relevant lag value of marginal product of $20.92, while Griliches (1964) found $16.52 for aggregate agricultural research and Peterson found $21.09 for poultry research (for a more extensive discussion, see Seldon 1985). Our estimate was close to the higher of the agricultural estimates, and this may be expected since SWPW research was applied in nature over the period used in this sample and could therefore be more easily adopted by producers. In addition, information is passed to *all* SWPW firms much more quickly than information is passed to *all* farmers.

The results of our estimation procedure are found in table 1. Here PV indicates present value of total benefits unadjusted for costs, NPV indicates net present values, BC indicates benefit-cost ratios, while subscripts CS, PS, and NEB mean consumer surplus, producer surplus, and net economic benefit, respectively. PV_{ET} is the present value of all expenditures. All values are in 1967 dollars.

According to our calculations, public investments in SWPW research were very productive, exhibiting an internal rate of return of 422 percent. Both producers and consumers benefited from the investments, although producers tended to gain somewhat more than consumers.

Our estimate of the internal rate of return to SWPW is higher than returns calculated in the agricultural economics literature, where rates of 90 to 110 percent are on the high side (although not uncommon—see Ruttan 1980). That the estimate would be larger is not surprising, given the applied nature of the research and the speed with which the information is passed to the private sector. An alternative model which assumes that public R&D in SWPW for 1972-1980 was qualitatively different from research through 1971 did not give very satisfactory statistical results; but applying those results for the period 1950 through 1971 still gives a high internal rate of return of 407 percent.

Table 1.--Returns to public research: nonresidual supply function estimates for the 1950-1980 program assuming a multiplier of .26

Productivity measures[1/]	Social discount rate[2/]		
	.04	.07	.10
PV_{CS_T}	2,752,501,319.35	1,391,652,548.17	770,454,508.96
PV_{PS_T}	3,053,037,570.26	1,543,602,353.41	854,577,814.55
PV_{NEB_T}	5,805,538,889.61	2,935,254,901.57	1,625,032,323.51
NPV_{CS_T}	2,722,232,580.56	1,371,274,900.45	755,988,826.17
NPV_{PS_T}	3,022,768,831.48	1,523,224,705.69	840,112,131.75
NPV_{NEB_T}	5,775,270,150.83	2,914,877,253.85	1,610,566,640.72
BC_{CS_T}	87.44/1	63.83/1	48.42/1
BC_{PS_T}	96.98/1	70.79/1	53.71/1
BC_{NEB_T}	184.42/1	134.62/1	102.12/1
PV_{E_T}	31,479,488.71	21,804,082.72	15,912,250.84

1/ PV = present value of total benefits unadjusted for costs
NPV = not present values
BC = benefit/cost ratios
Subscripts
CS = consumer surplus
PS = producer surplus
NEB = net economic benefit
PV_{ET} = present value of all expenditures

2/ Internal rate of return: 422 percent

SUMMARY AND CONCLUSION

In this paper we have developed a nonresidual supply function approach for estimating returns to research. This method is a straightforward extension of the production function approach commonly used in investigations of the marginal productivity of research. The method uses past R&D as an exogenous shift variable for the supply equation and can therefore be used to estimate returns to research under *ceteris paribus* conditions where a supply curve can be assumed.

While the approach is as data-intensive as the production function approach, the variables are usually more conveniently available than those needed to estimate a production function, and we can get all the information that the production function provides by estimating the production function parameters directly from the derived supply equation. Furthermore, this nonresidual supply function approach will credit research with retarding an inward shift of the supply curve due to, perhaps, a rising real wage rate or cost of capital. The residual approach could not be used under these conditions.

When we applied this methodology to public research in SWPW production over the period 1950 through 1980, we found that the internal rate of return to public research was high—422 percent or better. Consumers and producers benefitted, although producers tended to gain more surplus through public research than did consumers.

That the internal rate of return to SWPW research is higher than commonly found in agricultural studies is not surprising. Public research in SWPW over this period was applied research that was quickly adopted by SWPW producers. In contrast, agricultural research is often more basic, requiring years of research to obtain results that can then only be disseminated to the users over a fairly long period through extension efforts. Thus, costs are incurred for any particular project over a rather long time horizon, resulting in relatively high costs and highly discounted benefits.

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SUMMARY: PRODUCTIVITY IMPACTS OF TREE IMPROVEMENT RESEARCH IN THE NORTH CENTRAL REGION

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The North Central Region Project NC-99, "Forest Tree Improvement—Selection, Breeding and Seed Production," was initiated in 1960 and is currently in its fifth phase. Administered principally by the 12 State agricultural experiment stations in the North Central region, the project also involves formal and informal cooperative research ties with two U.S. Forest Service Research Laboratories, the Ohio Agricultural Research Service Station, Southern Illinois University, State agencies, industry, and neighboring Canadian provinces. The NC-99 project is generally perceived as a successful example of cooperative tree improvement research. By pooling their efforts, members of the cooperative have been able to undertake a greater variety of research and to conduct it more effectively than if they had worked alone. Over the past two decades, the NC-99 project has conducted provenance tests of 40 species, of which 13 are currently ready for use in establishing genetically superior seed orchards.

The overall goal of this study is to evaluate the impacts of NC-99 research and the application of knowledge generated by that research. This task is complicated by the wide variety of species and physical characteristics addressed by the participating researchers, and by the basic as well as applied nature of tree-breeding research. In addition, while the applied research results tend to be specific to the region, the results of basic research on tree biology are often of a more general nature.

A first step in the study will be to determine the cumulative investment in NC-99 research since 1960. Quantification of research benefits in economic terms will, for reasons outlined above, concentrate primarily on productivity gains realized from production of genetically superior trees. This comparison of costs and benefits is expected to be similar to previous analyses of tree improvement programs for single species. It is commonly referred to as an *ex ante* benefit/cost study. The *ex ante* approach is necessary because the genetics studies and tree improvement programs have not progressed to the point where historical performance data are available.

Evaluation of the productivity of the basic research component of the NC-99 project is expected to rely on a "partial indicators" measure. This approach has merit when attempting to measure the contribution to knowledge of a research group, such as the NC-99 project. It is most useful for gauging the output of one research laboratory or project relative to others working on similar problems. It is not intended as a procedure for measuring the productivity of individual scientists. Variables in the set of "partial indicators" might include number of scientists trained, publications, citation patterns, coauthorship patterns, and peer evaluations. While the results of this approach are qualitative, they do provide research administrators with an indication of scientific performance.

RETURNS TO INVESTMENT IN FORESTRY RESEARCH: THE CASE OF CONTAINERIZED FOREST TREE SEEDLINGS[1]

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There is extensive evidence that research has a significant effect on increases in productivity, which in turn has a positive effect on economic growth and development. A substantial amount of evaluation effort has been devoted to agricultural research and extension to measure these gains, but comparatively little has been done in forestry. It is likely that research evaluations and other forms of technology assessments will play an increasingly important role in the future of publicly supported agricultural and forestry research due to a recent court case (California Rural Legal Assistance (CRLA) and Public Advocates, Inc. vs. University of California) on the West Coast (Kendrick 1984). Evidence of this heightened interest in evaluating forestry research directions, methods, results, and impacts is provided by this workshop.

This study analyzes the economic impacts of research which led to the adoption of containerized forest tree seedlings (CFTS) in this country as a method of forest regeneration. A containerized seedling is a tree grown in a container, under controlled environmental conditions, in a relatively short period. This regeneration technique is contrasted to bareroot seedling production, where seedlings are grown in exposed seedbeds using specialized farming practices, removed from the soil and shipped to the planting site with the roots bare (Tinus and McDonald 1979).

RESEARCH BENEFITS

Economic benefits resulting from the development and utilization of CFTS technology come from the lowered cost of producing established seedlings, and employment effects, among others. This study considers only benefits measurable in terms of lower costs of production and hence consumer prices, and those resulting from a more flexible operation and the extension of the planting season.

The economic surplus model adapted to evaluate CFTS research benefits follows that of Griliches (1958). The theory behind this approach is that the adoption of technological innovations resulting from research and development reduces the marginal cost of production, increasing production and lowering the market price. The gross annual research benefit (B*) was calculated using the formula:

$$B^* = kP_{br}Q_{cs}(1-1/2kn) \ ,$$

where k is a percentage measure of the price discount of CFTS, or $(P_{br} - P_{cs})/P_{br}$; P is the cost of seedlings (measured per thousand), Q_{cs} is the estimated quantity of CFTS produced annually, and n is the absolute value of the price elasticity of demand for CFTS.

Values used to determine the variable k are based on bareroot and CFTS price differences in the form:

$$P = [(PR + TH + SP)/SL]$$

where PR represents production costs, TH transportation/handling costs, and SP site preparation and planting costs, and where SL is the survival rate following the model developed by Colby and Lewis (1973).

RESEARCH COSTS

Economic costs resulting from CFTS research are direct costs (e.g., salaries and supplies), indirect costs (e.g., staff training and management, opportunity costs), and complementary costs (formal and informal technology transfer costs).

Public and private agencies have supported and conducted CFTS research in the U.S. since approxi-

[1]*Research supported by the College of Forestry and Agricultural Experiment Station, University of Minnesota and the USDA Forest Service, North Central Forest Experiment Station, and Cooperative State Research Service.*

mately 1969. Costs associated with this effort are estimated following the methodology developed by Bengston (1984), who used screened publication counts as an indicator of public sector research activity combined with information about cost per scientist year, industry estimates of private sector research, and deflation with a cost of research index. This technique is used because the scope and diffuse nature of the CFTS research effort precludes the use of financial records to account for costs, and published government data are not available.

RATE OF RETURN

The internal rate of return to investment in CFTS research can be readily calculated once benefits and costs are estimated. This measure gives an indication of the highest interest rate at which money could be borrowed to finance the total research budget and still not incur a loss on the investment. Rates of return were found ranging from 37.3 to 111.2 percent under different assumptions concerning research benefits and costs (table 1).

The internal rate of return proved to be very sensitive to the price discount of CFTS (k) estimate that is used, and also to estimates of research cost levels (varied plus and minus 33 percent). Varying projections of the estimated quantity of CFTS (Q_{cs}) produced in the future did not significantly alter the results, though this may be due to the fact that the two projections made were not widely divergent.

Research evaluations such as this can supply background information, provide support for decisions already made (or provide input into changing decisions, if results so indicate), and give verification or refutation of ideas (Gregersen 1983). Elmer Staats, former Comptroller General of the United States notes: "In the final analysis, the hard choices will be political choices, but political leaders and the public need increased awareness of the arguments, pro and con, concerning the choices that must be made. Those who want to do right should at least be equipped with good information" (Staats 1974).

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Table 1.--Internal rate of return to containerized forest tree seedling research under different assumptions concerning research benefits and costs[1/]

Research costs[2/]	Case A[3/]		Case B[4/]	
	k = Upper [5/]	k = Lower [6/]	k = Upper [5/]	k = Lower [6/]
X	89.2%	54.2%	89.1%	53.8%
+33%	74.5%	38.4%	74.4%	37.3%
-33%	111.2%	74.7%	111.2%	74.6%

1/ Combining public and private containerized forest tree seedling research.
2/ Research costs: X: mean research costs estimates; +33%: upper level research cost assumptions; -33%: lower level research cost assumptions.
3/ Upper level Q_{CS} assumptions.
4/ Lower level Q_{CS} assumptions.
5/ Mean price discount of containerized forest tree seedlings (substitute: bareroot seedlings).
6/ 1/2 k.

FUTURE AREAS OF RESEARCH

THE FUTURE DIRECTION OF FORESTRY RESEARCH EVALUATION EFFORTS

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Science is dynamic. It is evolutionary in nature, building upon what has gone on before. New ideas, new hypotheses, are the mutations of scientific knowledge, spurring development in unforseeable directions. Lines of scientific inquiry are born, they flourish, they die. They evolve into new lines of science. We can forecast promising areas of development in science, for the near future, but we cannot forecast the future of scientific knowledge over the long run. Fields of scientific knowledge continuously evolve, although often not along neat, orderly lines. Nevertheless, a knowledge of where we have come from, and where we are now, can help us estimate where we may go in the future.

In many fields of science, the development of research activities tends to follow a distinctive pattern. A new, relatively unexplored field of science may first go through a descriptive phase for a period of time, where scientists are primarily observing and reporting on case histories or on the results of particular experiments. This phase builds up a rich body of literature about individual occurrences. At some point, scientists begin trying to explain these observations within a more general theoretical framework.

This development of new theory is often based upon a leap of imagination and faith on the part of one individual or a small group of people.

A period of testing competing hypotheses follows, until some theory is generally accepted by the profession. This may take a generation or more. This new accepted theory becomes the doctrine of the field, and is taught to young, incoming scientists as part of the accepted knowledge base of the field. These new scientists, steeped in the new paradigm, are able to fully exploit this new organization of knowledge. Progress within a field is often rapid at this stage. Much of the research conducted during this stage fills gaps in existing knowledge by applying generally accepted methods and techniques to new problems or new areas, or modifying existing methods and techniques to improve on solutions to problems. But rarely are the accepted problems challenged.

Thomas Kuhn (1970) and others have traced through scenarios of periodic revolutions in science. At any one time in a field of science there is a generally accepted body of data, theories, and explanations of how things are. Anomalies arise in applying accepted theories to explain reported observations. New theoretical constructions are proposed to explain these anomalies. Often these new theories are radical departures from accepted theory, and can be termed revolutions. When such a theory is advanced it is often greeted with ridicule and outright opposition by the affirmed leaders of the profession. The term "revolution" is often particularly apt because the development of a new theory or school of thought within a profession can create some real conflicts among members of the profession. The history of science is filled with stories of the divisive influence of new ideas within a field of knowledge. Professional reputations are made and broken in this battle over competing theories.

What has this got to do with a discussion of the future direction of forestry research evaluation? Well, we can ask ourselves, "In what stage of scientific development is research evaluation at this time?" And, in particular, we can ask, "In what stage of development is forestry research evaluation?" Answering this may help us to forecast its future development.

Is there a well-developed general science of research evaluation? I think not. When we look at the literature, we find many people in many fields hard at work conducting research on research, each examining a particular aspect of scientific research using particular tools and techniques developed within their discipline. Research evaluation seems to be a relatively new, fragmented area of science that shows several promising areas of research. Several independent traditions of scientific inquiry have evolved over the last decade. I won't take time to enumerate them here. I have reported on them elsewhere (for example, Lundgren 1983). If you are interested I can provide you with an annotated bibliography that explores the literature in many of these fields.

There is a lot of interesting work being done in forestry research evaluation, but I have not yet seen a definitive, comprehensive statement of the research evaluation problem, let alone a synthetic theory of research evaluation. I believe that it is something we can look forward to during the next decade or two. At least, I hope that someone can bring order into this fascinating field of inquiry. This presents a real challenge to all who are interested in the advancement of this science of science—this research on research.

The history of scientific ideas and technologies teaches us that whatever the future brings, there will undoubtedly be revolutionary new ideas and new technologies that we cannot foresee. There will be a number of surprises. We all are to some extent prisoners of our own ideas, our own images of the world. It is difficult, if not impossible, to foresee the revolutions in thought that are likely to occur in a given field. The small changes are not too difficult to forecast, but the big, revolutionary changes cannot be forecast. This is especially true if we are trying to forecast within our own field.

Those who are at the cutting edge of scientific knowledge can forecast how the most recent developments in thought within their field are likely to evolve in the near future, and how they might be used. But the true revolutions that may occur are difficult to imagine.

Research evaluation in forestry is a relatively new field. It is just now getting underway. Although there have been a few isolated studies over the past two decades, and some of these were good studies, until a few years ago there had been relatively little systematic effort to develop and apply evaluation techniques to the research process in forestry. We have heard about some of these newer studies this afternoon. But overall, the field of forestry research evaluation is going through the painful process of trying to identify what it is and what it should be doing, and trying to get organized to get on with the job.

Some may look upon this as a problem, others as an opportunity. Agricultural research has a rich tradition of research evaluation through the work of agricultural economists. Norton and Davis (1981) have recently reviewed work in this field. There has been a logical evolution of research and, as we are well aware, some of the leading efforts have been carried out here at the University of Minnesota's Department of Agricultural and Applied Economics.

Yet, perhaps we shouldn't be too envious of those doing research in agricultural research evaluation. In an established field of science, with traditional approaches to a problem, it is sometimes difficult to depart from traditional concerns and take a new look at problems in the field.

In forestry research evaluation we haven't established any traditional line of inquiry. This offers some exciting opportunities. We can take a fresh look at the research evaluation problem, building upon what has been done in agricultural economics and in many other fields as well.

I would like to see forestry research evaluation take a broad look at the entire research evaluation problem. Let's not confine ourselves to a narrow scope of work too soon, but explore the rich array of problems of interest to many different people in the research system—the funders of research, managers of research, doers of research, disseminators of research, and users of research, to name a few. Each of these groups has its own concerns about the research process. Addressing each concern may require different approaches.

During these early years of research on forestry research evaluation, I would like to see a sizable effort devoted to clearly identifying the major problems within forestry research evaluation and setting priorities on the issues uncovered. We have relatively limited resources to devote to this task. It is important that we allocate these scarce resources efficiently and effectively and justify our own research on research. It is worth keeping in mind an observation by Richard Bradfield that Vernon Ruttan quotes in his recent book, "Agricultural Research Policy" (Ruttan 1982), and that Vern repeated yesterday:

> There are many interesting research problems.
>
> Some of them are important.

There are many interesting problems in forestry research evaluation. But we need to identify the important problems as best we can, and concentrate our efforts on solving these. That is a lot easier to say than to do. But that presents a worthwhile challenge to all of us.

We won't insist that our panelists today provide us with insights as to future revolutions in thought in forestry research evaluation. But we are fortunate in having with us today two people who are at the cutting edge of research evaluation, and who can discuss some of the evolutions in thought that are likely to occur in the near future.

The first panelist is Dr. Burt Sundquist, whose name and achievements are familiar to everyone who has explored the literature on agricultural research evaluation. Dr. Sundquist is Professor in the

Department of Agricultural and Applied Economics here at the University of Minnesota. Some of his most recent innovative achievements have been in the exciting area of technology assessment (Sundquist *et al.* 1982b). If you haven't seen the trail-breaking work on technology assessment of commercial corn production in the U.S. by him and his colleagues, I urge you to look it over (Sundquist *et al.* 1982a). Dr. Sundquist is going to discuss the future of technology assessments as a methodology for evaluating research.

I believe that technology assessment is one of the most promising areas of research evaluation in forestry. To justify research expenditures in the future we are going to have to do a better job of estimating the direct and indirect impacts of research on society. It is not enough to look only at the aggregate costs and benefits of research. Some of the really critical issues, the important political ones, are the questions: Who pays for the research? Who bears the adverse impacts of implementing a new technology? Who benefits from the new technology? What effects will this new technology have on our natural resource base and on our environmental systems? These are some of the important issues addressed by technology assessment.

We are fortunate indeed to have with us Dr. Burt Sundquist to discuss the "Future of Technology Assessments."

The second member of the panel is Dr. Robert Buckman, Deputy Chief of the USDA Forest Service in charge of research programs. As head of the largest forestry research organization in the world, Dr. Buckman has played a key role in developing an interest in forestry research evaluation in the U.S. It was through his initiative that the Forest Service a few years ago began a national effort to develop methods for evaluating forestry research, a program that Chris Risbrudt now heads. Dr. Buckman also is Vice President of IUFRO, the International Union of Forestry Research Organizations, for the period 1981 to 1986. As an officer of IUFRO, he has instituted some major new initiatives to strengthen forestry research among the developing nations of the world. He will use his extensive background in research administration to explore with us some of the future directions of forestry research evaluation.

As a research administrator, one of the questions that Dr. Buckman undoubtedly must ask himself is, "Just how much effort should we put into research evaluation?" After all, research evaluation is not a free good. It would be well to ask ourselves, "What are the costs and benefits of forestry research evaluation?" Research evaluators must also justify their requests for funds. That presents an interesting challenge for the future. How can we evaluate the evaluators? And who will evaluate the evaluators? I am reminded of that famous bit of poetry by Jonathan Swift:

> So, naturalists observe, a flea
> Hath smaller fleas that on him prey;
> And these have smaller still to bite 'em;
> And so proceed *ad infinitum*."

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THE FUTURE OF TECHNOLOGY ASSESSMENTS

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When one views technology assessment in an evaluative kind of mode, clearly one is starting out with the presumption there is some strong linkage between research and development investments and activities and the generation of technology. Some of those linkages are fuzzy and indirect, and it is hard to draw direct lines in some cases between research investments and the technology that flows out of them. Yet, if we are talking about the production and use of technology as such, but in the context of research evaluation, it is that very linkage we assume is an important one. I come at this whole area of research evaluation and technology evaluation from a pragmatic viewpoint. We are not going to conduct one big evaluative effort that is going to answer all questions or deal with all problems. Rather, we are in a situation where the need is to surround questions with as much information as we can, and then try to draw some inferences from that set of information. I would certainly say that there are a variety of evaluative tools that can contribute very substantially. Technology assessment, as such, might be thought of as only one of them, and yet in another context almost any kind of evaluative effort, regardless of what kind of analytical methods or framework it uses, comes under the heading of technology assessment. By that I mean that I see technology assessment as a very broad kind of umbrella.

I like to use a broad and boundless definition of technology assessment. Technology assessment is the formal, systematic, interdisciplinary examination of an existing, newly emerging or prospective technology with the objective of identifying and estimating first and second order costs and consequences, over time, in terms of the economic, social, demographic, environmental, legal, political, institutional and other possible impacts of the technology, including those consequences which may not have been anticipated, intended, or desired by the inventors, and of specifying the full range of alternative courses of action for managing, modifying, or monitoring the effects of the technology. It is pretty hard to envision something in an evaluative mode that doesn't fit under this definition in one way or another. The other thing I think that one ought to get out of this definition is that technology assessment per se does not dictate to the analyst what kind of analytical technique to use in the process. It might well be that in the conduct of a technology assessment effort one could, at different stages, use all the analytical techniques available to the economist, from regression analysis to optimizing analytical tools, to simulation techniques, and so forth. I want to suggest at the outset that in using a technology assessment framework we are not really locked into any specific kind of analytical device. Basically, I think that is the way inquiry ought to proceed. One ought not to start out with an analytical technique and then try to apply it to some question whether or not it fits. I think one ought to start out with a broader problem setting and then move to sort out the appropriate analytical techniques to use.

Finally, as a word of introduction, one of the real dangers of the technology assessment framework is that it is so broad and general that one can end up not having gotten down to the nitty-gritty of performing specific analyses. To some extent I feel a little guilty of that in some parts of our corn technology assessment.

Let me describe a framework that we tried to use in looking at a variety of technologies that impacted on the corn production sector (table 1). As people here have suggested, one of the obvious problems is that individual technologies are not spawned independently of what is going on in the whole system. Technologies are interrelated. Yet, if one starts out with the idea that because they are interrelated you can't separate them, you can't do anything about assessing individual technologies, and that is a conclusion that doesn't get you very far. I think, rather, one has to start out with the idea that there is indeed some degree of separability, but one needs to keep in mind that individual technologies are interrelated.

In any kind of technology assessment there is a need to talk about definitions, directions, and magnitudes of the technology and then define specifically the kinds of effects one will gauge that technology against. In the case of our corn technology

Table 1.--Framework for technology assessment

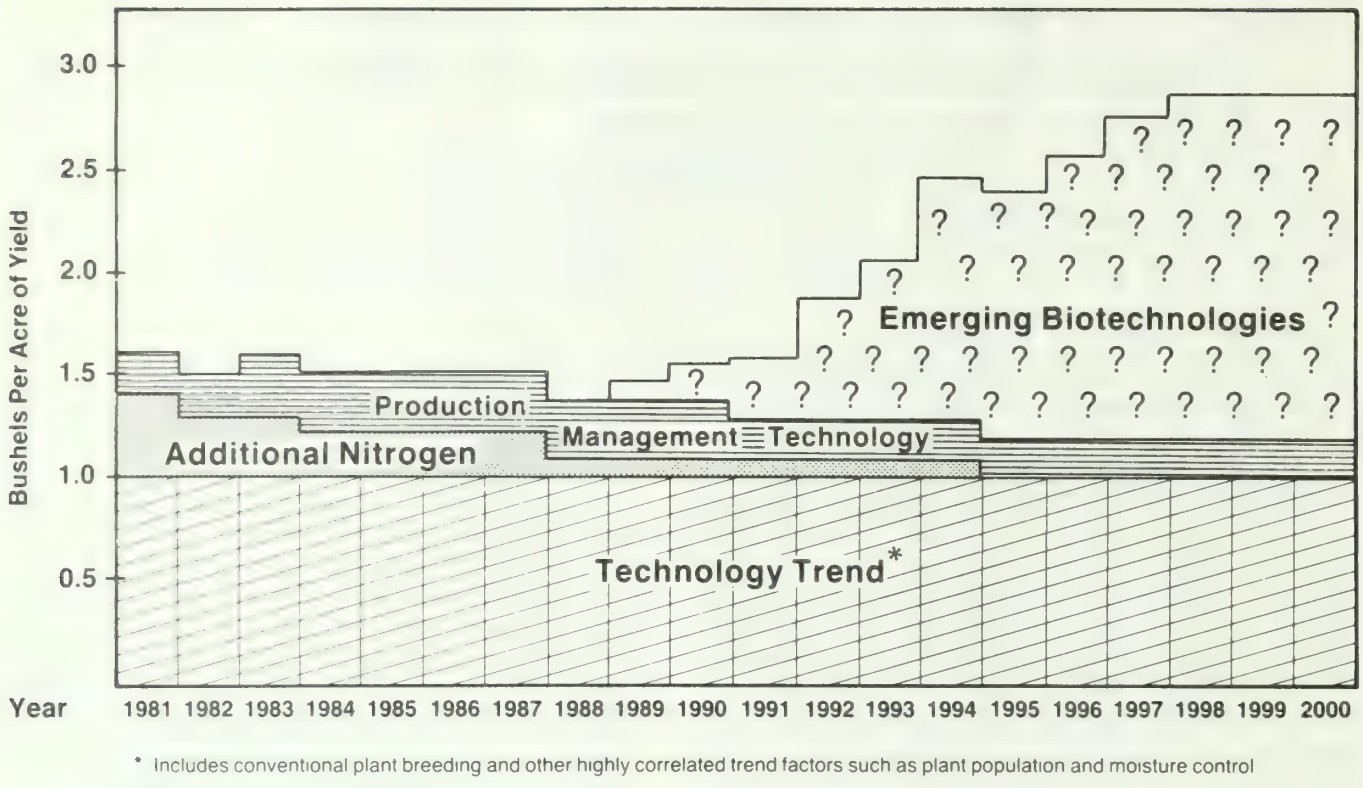
1. Definition and description of technology.
2. Direction and magnitude of technology.
3. Direct effects of technology on:
   A. Yields, costs, profits, production capability.
   B. Productivity.
   C. Input demand.
   D. Economic, environmental, legal, social, institutional, etc. considerations.
4. Indirect effects of technology on:
   A. Gainers vs. losers.
   B. Long term effects.
   C. Risk and uncertainty.
5. Feasibility of technology.
6. Alternative technology options.

assessment, we centered strongly on a set of evaluative criteria dealing with yields, costs, profits, and production capacity, those listed under item three A, B, and C (table 1). When it came to section D, we took the approach of raising these questions while realizing that we were going to deal with them very inadequately in a limited amount of time and with a limited effort. This framework is a useful next step after one has talked about technology assessment in complete generality. This starts getting down to the topics and issues that you can think about, what kind of data there are to work with or which can be developed, and what kind of analytical framework can be used. Rather clearly, some other evaluative techniques, such as the rate of return or other kinds of analysis, would just start at a point in this framework and move to a rather specific end, whereas the technology assessment framework in general has a lot of flexibility. Even if one finds he can't do too much on the individual subtopics (in table 1), it is still useful to set them out, identify them, and ask the question of whether or not you can do something meaningful in an evaluative mode. I think that it makes some sense to raise questions about the feasibility of the technology and how it relates to the alternatives available. Looking at things in a tradeoff or alternative framework is a useful device in generating perspective, compared with just looking at the technology without some reference to the alternatives that are available.

Finally, in our technology assessment for corn we were really assessing historical technologies. Yet, I think one can use that historical analysis to sort out the important factors and project them into the future. One of the significant things that we concluded was that in the case of corn production, some of the old technologies during the 50's and 60's, such as nitrogen fertilizer, had dramatic impacts. Yet, as we moved into the analysis and measured the marginal product of an additional pound of nitrogen in the 70's, it was only about 20 percent of the marginal product of an additional pound of nitrogen in the 50's and 60's. For an obvious set of reasons, we were observing the law of diminishing returns in action. By the 70's almost all corn producers were using nitrogen and at very high levels. So I think one can get some feeling about the future from looking at past events. We did do some heuristic analysis of the emerging biotechnologies that might be applied to corn production. One of the conclusions was that, if we are going to get major future increases in productivity, and a yield gain beyond the fairly consistent increase of about a bushel a year that is associated with traditional breeding of improved varieties, it is going to depend heavily on this area of the emerging biotechnologies (figure 1).

Largely as a result of that, I and a couple of colleagues have two fairly significant efforts going at the moment trying to evaluate the time path and a potential payoff for investments in the emerging biotechnologies. I think anything we can do to uncover things in this area is going to be useful. Even if one looks at the role of the emerging biotechnologies in plant production, as compared with animal production, there are some very different recognizable benefits. The more immediate ones appear highly related to the livestock sector, whereas in the longer term, the major payoff might well be in applications to plant production.

Let me summarize a couple of the advantages of the technology assessment framework (table 2). It does permit the use of multiple criteria for evaluation. In this framework one can evaluate against a whole variety of criteria, from energy efficiency to cost efficiency, to general productivity, to externalities generated by the technology, etc. And it has a



* Includes conventional plant breeding and other highly correlated trend factors such as plant population and moisture control

Figure 1.—*Projected marginal impacts on corn yields by various technologies, 1981-2000.*

good deal of flexibility. At least conceptually, one can consider both market and nonmarket criteria, whereas in rate of return analyses one is pretty much restricted to market criteria, and to shifts in supplies and prices. That doesn't mean that it is easy to come up with nonmarket criteria, and I think that is a problem we all face. Technology assessment does permit the evaluation of a whole production system, and the linkages within that system. It leaves wide open the question of appropriate analytical proce-

Table 2.--Characteristics of technology assessments

ADVANTAGES OF TECHNOLOGY ASSESSMENT FRAMEWORK
1. Permits multiple-criteria framework of evaluation.
2. Flexibility.
3. Can consider both "market" and "nonmarket" criteria.
4. Permits evaluation of the whole production system and its linkages.
5. Does not exclude any analytical procedures and uses information from any source.
DISADVANTAGES OF TECHNOLOGY ASSESSMENT FRAMEWORK
1. May not generate unique (specific) answers to questions under consideration.
2. Analytical framework is somewhat "ad hoc."
3. Framework does not, by itself, provide a "weighting basis" for multiple criteria.
4. Technologies are often not independent of each other.
5. Interaction of price and technology can alter the outcome.
6. There is a tradeoff between narrower, in-depth evaluation and a broader technology assessment type.

dures, and one can utilize information from any source. One of the handicaps of being locked into just a single analytical technique is that you can't find a way to effectively use some of the information that is available. One can focus on different dimensions and technologies, depending on what the assessment objectives are. In retrospect, I think one of the problems we had with the corn technology work was that we didn't narrow it down tightly enough as to what our assessment objectives were. We could have narrowed it down and made it more specifically an assessment of past and future research investments. It's important to have firmly in mind what your assessment objectives are.

Then, on the other side of the ledger in broad terms, one has some inherent disadvantages associated with technology assessment (table 2). First of all, it may not generate unique or specific answers to questions that are under consideration. You may not specify the objective functions that are going to answer the questions that you want. Some people would argue the analytical framework is likely to end up being somewhat *ad hoc* because there is no specific analytical technique that the technology assessment framework directs you to.

One can, and probably does, end up with an eclectic kind of analytical framework. The framework does not, by itself, provide any weighting basis for individual criteria when you have multiple criteria, such as productivity, energy efficiency, or something else.

One other problem is that technologies are often not independent of each other. There are a variety of interactions of other developments along with technology that can alter the impact of the technology. I would take a strong position that technology assessment is not a substitute for narrow, in-depth evaluations of technologies, because one is almost by definition faced with having to aggregate over some of the details of individual technologies. In fact, particularly with respect to the emerging biotechnologies, when we tried to get highly technical we started encountering conflict between individual scientists. There was a point beyond which, if we tried to get more detail, we were in fact trying get into the highly technical area of new technology which we couldn't do effectively for a couple of reasons.

First, we didn't have the intimate technical know-how that was needed. Second, when you get too near the very frontier of what is going on in research, then you find very capable scientists with very different feelings about things, and it is pretty hard as an economist to say who is right and who is wrong.

My final comment would be to suggest that the future of technology assessment has to be very bright, both from the standpoint of a mechanism to look at the question of evaluating investments in research and development, and also from the standpoint of being able to deal with multiple criteria. I think the time has come and gone when we could impose on society a judgment about whether a technology is good or bad, or desirable or undesirable, without looking at something more than just a rate of return or a simple productivity gain number. I think we must have a broader framework. That doesn't mean we must have it in each individual research evaluation activity, but somewhere along the line in making judgments about research investments, and technologies, we have to be able to look at more than just a single criterion of profitability, or productivity gain, or whatever. I would urge people in utilizing this kind of a framework to start out with the notion that evaluation can be pretty broad. Try to specify a broad framework, then work down to the more specific things that can be done within your set of resources, data, and analytical capabilities. I like that direction much better than starting out with an analytical technique and looking for a set of data to which it can be applied.

SUMMARY: REFLECTIONS ON FORESTRY RESEARCH EVALUATIONS

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Washington, DC

THE POLITICS OF SCIENCE AND BUDGETING

I would like to make a few observations on science in forestry. Much of my perspective deals with the politics of science and budgeting. Yesterday, John Fedkiw mentioned the introduction by Robert McNamara in the late 1960's of Program Planning and Budgeting (PPB) to the Federal government. John and I worked together in those days along with Clark Row, Bob Marty, and others. I accepted the PPB system with much enthusiasm; I thought here was a way to develop a rationale for science programs that would be useful. I ended the PPB era with a great deal of disenchantment. With the exception of the tree improvement work in loblolly pine, I found the PPB exercise demanding of information and extremely sensitive to assumptions. I had the feeling that the analysis often frustrated or thwarted research programs rather than enhancing them.

In the same vein, a high-level science administrator in the USDA observed that almost none of the changes we see in science policies in the Federal government were initiated by evaluations. For example, the space program wasn't the result of an evaluation, it was a response to the Russians' launch of Sputnik and its implications for national defense. A few years later President Kennedy said we were going to put a man on the moon in 10 years, a goal around which everyone, for a variety of reasons, could rally. Today space programs still claim about $5 billion of the research budget of the Federal government.

And human health programs have grown enormously in the last two or three decades, but not as a result of formal evaluations. Those advances came from the fact that Mary Lasker prowled the halls of Congress, lobbying for various health institutes in the Federal government. I think human health research is now over $5 billion per year.

My point is that evaluations play a relatively small role in the development of Federal science programs. However, as John Fedkiw said yesterday, in order to take advantage of opportunities that come along there needs to be a credibility, a legitimacy, and an understanding of science. And that's what leads us into the study and evaluation of science and the education process itself.

THE NEED FOR EVALUATIONS

Evaluation activities, as I said earlier, give a legitimacy and a credibility to research. We must all recognize that budgeting is still largely a political process. In presentations of budgets with the Chief, I serve as an advocate for my programs and he normally serves as an adversary. When the Chief presents the Forest Service budget to the Secretary of Agriculture, he tends to serve as an advocate for the agency budget and the Secretary and his staff play the role of adversaries. And I am sure that when the Secretary talks to the Office of Management and Budget, he serves as an advocate for the Department budget. So we have role reversals among participants, a process I consider to be entirely rational.

Publicly supported research is strongly conditioned by political and social concerns, whereas evaluation is not. It is the absence of this influence that makes evaluations useful. There are several areas where I think that we need help from evaluation in better justifying and allocating research effort.

Evaluations of Noncommodity Resources

The first is a need to address noncommodity items, which do not enter the marketplace and therefore do not have traditional economic value. Examples include recreation, urban forestry, wildlife, and water resources. The Congress, in the last few years, has shown some inclination to support those items in

National Forest Systems programs. The outdoor recreation management budget for the Forest Service alone is now in excess of $100 million, yet the research program that supports outdoor recreation management is in serious decline. Up to this point our best argument for the recreation research program is that it backstops a more than $100 million outdoor recreation management program in National Forest Systems, and also provides valuable input to the outdoor recreation management programs of the Corps of Engineers, the Bureau of Land Management, the National Park Service, and the Fish and Wildlife Service. Somewhat over a billion dollars of Federal funds are spent each year on outdoor recreation management programs, and, with the exception of the Forest Service, there are no research programs in any of the management agencies mentioned above. We need evaluations to further analyze noncommodity research programs.

Evaluations of Sustaining Research

A second area where evaluation can help justify and enhance understanding is in maintenance or sustaining research. As the years go by, I have become more and more sensitive to this issue, but it is still difficult to articulate it well. We tend to describe research programs in terms of emerging issues and new problems. In the last 2 or 3 years, whenever one of these issues has surfaced, the policy response has been, "That's a good idea, let's do it, but within the budget you already have." That has been the reaction to research in acid rain, old growth-dependent wildlife, and others. But I have come to realize that a majority of our program is sustaining and continuing research, without which productivity levels would decline. These maintenance research programs do not result in great gains in the availability of a resource; rather, they allow us to maintain what we currently have. Maintenance research is terribly important to the well-being of the forestry economic sector, and I suspect this is true in agriculture as well.

An example of maintenance or sustaining research is prescribed burning. This is a growing technology and one that ought to be used more on forest land nationwide. However, the risks for those who use fire are high, as the reward system doesn't recognize the successful use of fire nearly as well as it administers sanctions for the misuse of fire. I am reasonably sure that if we were to drop that sustaining or base research program in fire, we would see a decline in the use of prescribed burning. It's important to have a research presence, to feed new technology into prescribed burning, and have a source of information and support for those people who are administering fires under risky conditions.

Another area where sustaining research is important is in reforestation and regeneration. As reforestation research declines and we go through one or two generations of new district rangers and new foresters, we begin to see a decline in the quality of regeneration programs. Reforestation specialists continue to depend on the most up-to-date information on regeneration techniques, brush control methods, and site preparation methods to perform their jobs well.

Role of Education in Science

A third area where I think we need evaluation assistance is in the link between education and technological innovation. We need to study the relationship between formal and informal education on one hand and research on the other. My impression is that our extension activities in forestry are much less than they are in agriculture. It's an area that needs additional examination, and I hope we can join with the Cooperative Extension Service, State foresters, and State and Private Forestry to take a better look at that linkage. Education, both formal and informal, always gets high marks as a contributor to technological change.

Historical Perspective

A fourth area in research evaluation studies the evolution of science policy and management in forestry over time. In my estimation, one of the least understood stories in conservation is the resurgence of the forest resources in the South. It is the premier story in forest conservation in the world, exceeding the eucalyptus story, the poplar story, the *Pinus radiata* story, and perhaps all of them combined. Yet it is a story that is not well told. In the early days in the South, a relatively unsophisticated technology required getting livestock off the range, hogs out of the woods, and particularly stopping fires. Education played a major role in these changes, along with some important legislation. Fifty years ago much of the South was worn-out cotton fields and broom sedge; very soon the South will provide 50 percent of the forest products harvest in this Nation. It is substantial disservice not to understand what science and education contributed to this remarkable story.

I want to reemphasize again the point that we must keep in mind the historical contribution of science and education. We had one Regional Forester who not so long ago said, "You know, I can't think of anything that research has ever done for me." I would like to have placed some well chosen case histories in front of him.

Secondary Consequences

My fifth point, which has been addressed by others, concerns the second- and third-order consequences of science. These consequences, including income redistribution and social and environmental impacts, are examined in technology assessments. A favorite question of former Forest Service Chief John McGuire was, "What do our policies have to do with industry concentration, or the lack of it?" There are a multitude of these issues that we must begin to explore, but I realize that it is far easier to frame questions than it is to deliver answers. The set of second- and third-order issues that Sundquist and others have described in their technology assessment of maize illustrates a pattern that we could well adopt in forestry.

Science as a Policy Issue

My last point has to do with the consequences of science as a policy issue, as a factor of productivity in its own right. One of the most memorable sessions that I attended in my years in Washington was the prime agricultural land seminar sponsored by Resources for the Future. The genesis of that study had to do with the consequences of increasing urbanization, transportation, and utility corridors on prime agricultural land in the U.S. The discussion quickly developed into the role of technological change in agriculture. Emery Castle made the point that about 2 percent of our lands are going into urbanization, and there is some indication that that may be running full course. He also indicated that an additional 2 percent of the land is going into transportation and utility corridors, and that too may be running full course. But despite these declines, over the past 50 years, innovations from science have probably increased agricultural production by approximately 50 percent. Emery went on to say that perhaps we turn our attention to science policies because they will make more difference than all of the land withdrawals combined. I suspect that a similar pattern exists in forestry.

An example is the demand-dampening implications of truss-frame housing. If we had a 100 percent implementation of new truss-frame housing concept, the savings in timber volume would offset the timber supply consequences of all the RARE II areas on National Forests in the country. I am reasonably sure that truss-frame housing will never enjoy 100 percent implementation. However, this relatively low-cost technology has large implications for taking pressure off timber productions, thus liberating forest lands for other uses.

When I was here at the University of Minnesota 35 years ago the big issue was the advancing age of the logging labor force. What could we do about it? As it turned out, it was a nonissue, because we substituted capital for labor. One of the things that sticks in my mind is that in 1950, a 25-man camp in Koochiching County could put up 100 cords of wood in a week. When I was in northern Minnesota about 3 or 4 years ago, I saw a five-man crew put up the equivalent of 150 cords of wood in 1 day, all because of capital investments in modern machines—which in turn owed their existence to research and development.

There are policy implications in that logging example, and other examples like it that have arisen out of technological change, that we've not pursued. For example, I've always wondered why the environmentalists, who are seeking additional Federal lands for nontimber use, have never seized on the opportunity to substitute technology for land. If we would apply some of the technology currently available to forest lands that are potentially more productive, and environmentally less sensitive, we could have both timber and outdoor recreation. The larger issue here is that science and technology can be substituted for other factors of production such as land, labor, and capital. The role of science in substituting for the other factors of productivity deserves more attention in forestry. John Fedkiw pointed out the enormous gains in productivity in agriculture because of science. I suspect those gains also have taken place in forestry, but we simply haven't documented them very well.

DISCUSSION V

JOHN FEDKIW

You have to make some sort of decisions on technology, or where technology is going, in this whole area of technology assessment. Important questions you must deal with are what new technologies are coming, and what their quantitative impacts will be. I am curious as to how you go about making those decisions and getting consensus or can somehow be confident that yield is going to go up a certain amount, or the acreage required to produce a given amount is going to go down. These are very important pieces of information.

BURT SUNDQUIST

At some juncture one goes beyond the point at which systematic inquiry or research can add to the total information package. There is no question that a wide variety of factors enter in. One can start out with the idea of trying to assess what's happened in the recent past and then try to see what kind of factors are likely to constrain or augment that area of technology in the future. I don't think there is any simple answer to that question. I think that the more one can disaggregate and look inside the "black box," the better off one is, because it's very dangerous just to extend historical trends without taking a look at what kind of things are likely to impact on them.

JOHN FEDKIW

When you end up with a number, is it your decision or do you take the consensus of scientists working in this area? Is it your own, private assessment, based on inputs from other people, or is it a consensus decision by the key people in this area of work?

BURT SUNDQUIST

It's a combination of several things—a combination of the appraisal of so-called experts or scientists with respect to some areas, such as the emerging biotechnologies. With respect to the impact of nitrogen fertilizer, it flows out of the economic analysis based largely on what's been happening over the last 20 or 30 years and extending that. It seems to me that any reasonable appraisal of the future with respect to production, output, or yields has to use information from a combination of sources. In some areas, you have a good historical base to use a technique such as regression analysis. In the emerging biotechnologies, you don't have an historic database to work with, so it seems necessary to look to people who appear to be the best informed. In some cases, we talked to people in an effort to understand the importance of a given technology, how it operates, where it came from, and what the likely future of it is. For example, several people that we talked to for the assessment of corn technologies were breeders, several others had worked intensively with such things as corn-drying technology, or irrigation technology. I would say with the exception of the emerging biotechnologies we didn't lean too much on these people to give us estimates of future impacts, or even partial impacts. We had them help us understand the technology of what brought the changes about, and how it related to other technologies.

DAVID LEWIS

Along the same line, given the 50 or so people who were involved in your assessment, would you get general consensus about the gains in corn production that we are going to get from the application of nitrogen, with a fall-off to zero in a certain time, and the same thing for management? The implication of all this is that we ought to concentrate the resources for corn research at least in biotechnology, because that's where the big payoff is. Can you get a consensus from the people in the corn program who would say that makes sense and that is the future direction?

BURT SUNDQUIST

I think we had a reasonable consensus; I tried out the preliminary results on people, and by and large they didn't find any substantial issues. When you look at those projections a little more closely, you see that there is something called a technology trend. But as a practical matter, we can spell that out in quite a bit of detail, and say that 95 percent of it is tied up in traditional plant breeding improvements, moisture control, etc.—but the biggest single item is plant breeding. There is also a significant improvement due to management and improved information and control systems—doing a better job of applying the technology that is currently available. Feeding into this are things like more systematic scouting with respect to disease and insect problems, and better control of irrigation technology, which is a significant variable. But I think our assessment of fertilizer technology is that it has made its major contribution.

That past contribution will continue to be there, but when you look at further increases in yields, well, we ran into a number of people saying that they're advising top corn farmers to cut back a little on fertilization. At the margin they're spending a dollar and maybe only getting a dollar back, and there are better places to spend their money.

ANNE FEGE

Dr. Buckman, most of your comments were directed toward lines of research, that is, subject areas we should look at in forestry. There is a whole other part of research evaluation that deals with how we can manage the existing lines of research better. My question is, what do you see as the most important questions from the standpoint of research managers, and how did those questions stack up against the list that you provided us?

ROBERT BUCKMAN

I think a fair amount of work has been done on the characteristics of researchers. When one gets to the smaller units of work—and publications and things of that sort are useful, provided you know something about the environment and the characteristics of the person you are dealing with—I am just terribly concerned that the error terms that go with some of the these correlations may be so large that the opportunity for some injustice is considerable. I think the most powerful tool we have for evaluating research is a peer review system. So anyway I don't mean to discourage you from using some of the techniques like citation indices, and numbers of publications or whatever, but I am still concerned about the size of the error terms that go with those.

ANNE FEGE

Is it important to reduce those by looking at whether some of these tools are some that we can use as research managers? I guess that's a more academic line of work to be worked on later, at least to take a look at whether it may or may not give some answers to management.

BILL HYDE

It seems to me there is a second-order effect you want to think of, looking at judging research by locations. I recently heard a Forest Service pioneer researcher speak and I am absolutely certain that he was serious. He commented that if it is publications that we want he will produce publications, and we all want to be very careful in this area. That's certainly not the intent of anybody here. But that can become one of the outcomes of some of our work.

ROBERT BUCKMAN

I am concerned that we will get goal displacement at the level I work at, if we put the emphasis on publications. Now I think one of the stations uses publications as a diagnostic tool, but they use it on almost a case-by-case basis. I think it is a powerful tool, but it requires a lot of judgment to go with it. Some of the questions we are called upon frequently in the budget process to answer are, how do you evaluate your research program? What kind of turnover do you have? How do you address new lines of work? So we do have to have a way of addressing those issues.

GARY EVANS

One of the indices that we use in CSRS, especially in the McIntire-Stennis program, is one similar to that question. We use it strictly as an index. We look within an institution at a number of graduate students, and number of publications per scientist, and we break the number of publications out into refereed and nonrefereed. It is just one of the many kinds of indices of research productivity that are available and can be used. And it helps us, as we look at 62 forestry units, across the country, involved in research, to maintain an index of which ones are coming up and which ones are dropping back. But again, the error term is so great that, all we can use, is a single-integer index.

ROBERT BUCKMAN

One of the areas of inquiry that I often thought could be useful, provided we can get around the Privacy Act, and the Freedom of Information Act, is the panel evaluation itself. The panel evaluations reflect a number of things, including a peer assessment, about how well the scientist is doing. I have often wondered if there are any opportunities to correlate the consequences of the peer review system with other characteristics of those scientists.

ANNE FEGE

You certainly have the promotion records, and we know how many years they have been in grade, and each time they go to panel. From an internal standpoint you may not be able to do it as an academic exercise, but that information is certainly available to station managers.

DENVER BURNS

Certainly information on publications is an indicator of a person's capability in many areas. I know some of the early work done at the North Central Station in the CRUSK study showed that the same people who published a lot are the same ones who perfected technology transfer, are called on for seminars, and receive recognition in other ways. All of those go together and relate to the figure stated earlier, that 47 percent of the publications are written by 14 percent of the scientists.

JOHN FEDKIW

As a final note, I refuse to work with policy questions and take those policy answers and build them into the assessment process without direct involvement of the policy client. The policy process is a way to involve the interest of policy officials, and provide them the opportunity to respond to new or improved information. Unless you have a policy official's interest in an issue, you may just not get much response. The strategy of providing information for policy issues is worth thinking about real hard.

ROBERT BUCKMAN

I'm hoping that a lot of this policy initiative, and the larger policy issues, will emerge from some of the studies I've heard about at this workshop. That's where they ought to arise. We tend to focus on the technologies and not so much on the policy questions stemming from them.

LYNN MAISH

It's clear that you're pretty much covering most of the waterfront in these studies, including those that might provide information useful for research management in the narrow sense, such as outputs in terms of publications. That kind of study is of very limited policy interest at the Department level, except that it is of interest to know that efforts are being made to look for ways to improve management. The fact that you're doing things like that is the main point for a USDA policy analyst. There are some other studies that seem to be providing some information for management purposes. A more in-depth look at how a project gets initiated, how you organize efforts to conduct the research, and so on would be useful. Dr. Buckman mentioned in his areas of interest some work with the interaction between extension and research, and facilitating the transfer of technology. That ties in with the question of how you choose a research project, design it, conduct it, and transfer the results.

The other day I was in a briefing on a very interesting study done in agricultural research. The USDA picked a number of successful research and technology transfers produced by ARS. They did a little case study on each one, and they had talked to the scientists on the project, and talked to user groups. The evaluators classified each of these cases by the extent to which user groups had been involved in the definition of the problem and design of the project, and by the extent to which there had been interaction between scientists and users during the conduct of research. Finally, they classed them by the nature of the dissemination of results—publication or presentation of the papers at a conference, active communication by the scientists to the users, or by the intermediary of extension. They classified all of the cases by those conditions, and then they talked to the users to get information as to which had been successfully adopted. The evaluators were able to draw a number of interesting conclusions from that kind of study. For example, in those where the dissemination of results had been very passive, a very low percentage were successfully adopted. The highest percentages of successful adoption were among those cases where they had high levels of interaction at all three points. That's an illustration of a study that might be useful in providing information in the organization and management of a research process.

This also gets to the point that we don't get the payoff of the research until the results are adopted. I noticed that we do have some studies on diffusion of results. I'm not sure whether any of these are in this broader context that goes all the way back to the interaction with the users and the actual initiative of the research, or interaction with extension. A number of studies are looking at rates of return, some in the narrow sense and some in the broader aggregate. Once you've established the credible, approximate levels of rates of return, then a lot of issues arise for which you need information beyond rates of return. This means that impact assessment or impact analysis must be done. It gets into questions of distribution of income, and other effects. Clearly you haven't gone very far in this sense, but it is of policy interest.

HANS GREGERSEN

Where do you see the agricultural research evaluation work going? Is it going towards more technology assessments, or will there be a broadening out of the rate of return studies? A lot of people seem to have decided that we have done enough of those.

BURT SUNDQUIST

I honestly believe that we have about enough of those, with the exception of trying to update them

through time and keep them current. Further evaluations probably ought to be more specific, or more functional area-specific. For example, even looking at corn technology, I would judge there's a lot of difference between additional mechanization research compared with biotechnology research, or plant breeding, or fertilization research. I think we have used up a lot of the potential with respect to mechanization, which has already driven the labor inputs in corn production down to less than 5 percent of the total costs. Moreover, we have only adopted part of the mechanization technology that's already available. If one compares further mechanization research with some other area of technology, or functional research such as plant reproduction, one ought to conclude that we should put additional mechanization technology lower down on the list of priorities than some other things. I think that kind of insight is very useful and you don't get it by doing aggregate rate of return studies. The aggregate rate of return can be very high and yet you can have a very substantial, very redundant research components in the system. So I think you have to try to get as much specificity as you can, whenever you can get it.

HANS GREGERSEN

So you actually see more disaggregation than in forestry research evaluation. We've been talking about a higher level of aggregation. You're saying you see some disaggregation, getting more specific research program evaluations.

BURT SUNDQUIST

It depends on where you start from. Looking at Federal livestock research in agriculture, I think that if we lump together the dairy sector, the cattle feeding sector, and the swine sector, we are aggregating over tremendous gains in some of those areas, but in some of them we've made very little gain. Poultry is very different from the rest. So to generalize from aggregate rates-of-return may generate as much misinformation as information.

So, keeping in mind where you can break out data and where there are definable lines of research, to the extent that you can trace those avenues, that would make more sense than doing a lot of additional rate of returns.

JOHN FEDKIW

The point here though is that this is ex ante, *which by definition isn't very useful if it's too aggregate, as opposed to* ex post. *That's a subtlety that's important. The National Academy of Sciences is developing some systems analysis methods to look at multiple variable behavior over time in response to different types of technology. They are trying to get at some of the subtleties of new technology, the interactions and side effects, which point in the direction of more complete and more effective technology assessment work.*

DAVID BENGSTON

One of the things we found in reviewing and assessing the agricultural research evaluation literature is that the number of empirical studies is beginning to taper off. Plotted over time, you get an "S" shaped curve which is on the decline. So perhaps there is a change in focus away from the rate of return studies and toward the broader technology assessments.

ALLEN LUNDGREN

This is interesting from the standpoint of developing a strategy for research. Of the inputs into corn production, the price of the labor component was only 5 percent. This means that at most, if you almost completely eliminate research on that component, you would only affect 5 percent of the total cost, in terms of cost reduction. Even if you were successful in further reducing it, you don't really gain much. Have you done this kind of analysis as a strategy for looking for opportunities to have major impacts on crop production systems? Have you explored that further—in other words looking for those places where, if you could have an effect, you would have a big impact?

BURT SUNDQUIST

Not in a major way except to conclude that we have pretty well mechanized our agricultural operation. As you proceed to utilize the major agricultural land resources which are available rather fully, this pushes you in the direction of assuming that any major future gain productivity will have to come out of increased output per unit of land. In other words, yield-increasing technology. It seems to me that this gives you some insight into the need to sort out those technologies that have yield-enhancing capability from those that don't. In some cases, it's difficult to sort out how much yield-enhancing capability a new technology of this or that type might have. But some technology appears to have very little yield-enhancing potential. And, in terms of the involvement of our technology and science generally, it's hard to put things at the top of the list unless they have at least some yield-enhancing capabilities.

JOHN FEDKIW

Of those seven items that Bob Buckman cited, the first three, as I understand it—the maintenance re-

search, noncommodity items, and the mitigating research—don't sell well. They don't sell, and I presume the reason for it is that people cannot visualize the benefits. But if you have something that is going to reduce costs and increase yields, they can see that and it may be adopted. Impact analysis is needed for some of the other areas. The role of research in influencing total productivity is understood. How much research has contributed to that is the quantification question. The second- and third-order consequences are also a part of quantified evaluation. When you're talking about the consequences of science on policy and productivity issues, productivity arguments do take you any place in a policy area until you have some numbers to talk about.

However, there comes a time when you have done enough program evaluation, ex post *perhaps, when more evaluation may not have a very high priority. After you have done enough* ex ante *studies, you perhaps learn how to be more selective about where you do it. We're still in a learning mode and the developmental stages of information analysis.*

GARY EVANS

One of the things I would be interested in hearing about from the group is the development of methodologies for evaluations on forestry research. What are some of the major frustrations? Where are the big holes? Several people have indicated that they're just now becoming able to define some kinds of quantitative evaluation techniques. In relation to the studies that we have in front of us, how did most of the people doing these studies feel about where the methodologies are? I think this would be of value to us as we look at supporting future evaluation projects.

HANS GREGERSEN

The real problem we face when we talk about methodology is fitting it to what information or data you have available. It's the old idea that in an economic development area people say that the economist isn't doing a decent job. It's because you don't have the production function data, you don't know what the physical input/output relationships are to put those values on. The economic part of it, I think, is fairly simple in most of those cases. It's really the relationships between physical inputs and outputs that we don't have and that's where I see the real challenges and problems—getting the kinds of physical input/output information that is needed. In agriculture, they've built up quite a solid base of information. If you're talking analytical techniques, I don't think that's really where the key issue is. I think we've got plenty of those around. Are you talking about methodology in a broad sense of data generation, too?

BILL HYDE

I think the data problem is overblown. Like I said yesterday, we can't let this hold us back, otherwise we would give up and clearly this isn't a time for giving up. Yes, the data problem is a very severe one. We have problems, for example, in estimating the benefits. We're collecting benefits industry-wide and the costs we're looking at are government costs. Clearly there are some private research costs, too. It's my understanding that there is an attempt by the National Forest Products Association (NFPA) and the Forest Service to develop better estimates of private costs. Meanwhile, we have to use all sorts of half-good methods to come up with industry costs or proxies for them. Furthermore, we have to start looking at biological research. Biological research investments create additional benefit estimation problems because of the long time periods involved. We are looking at production functions that are at an absolute minimum 25 years for any tree species. This means that we also need comparable data for 25 years ago and for today. We probably don't have it.

Among other things, such as the spillover issues, how much is forestry really gaining from the Finnish sawmill experts, or in a more extreme case, from the steel industry where we are getting better sawblades? What is the impact of the chemical industry on pulp and paper? We are just beginning to figure these things out. And what about development and retooling costs. It is awfully easy to overlook these altogether and, thereby, overestimate net research benefits.

DAVID BENGSTON

I have one comment on holes in the methodology. When I look at the studies that have been done, the agricultural studies and others, one thing that I see is a lot of very naive assumptions about the future diffusion of innovations. Often, extremely simple assumptions are made to handle that. There's a wealth of information and a large array of techniques in technological forecasting that would be useful to research evaluators. Stier has done some work in this area on diffusion of the sulfate pulping process. That's one of the few studies that has tried to forecast the diffusion of a major innovation in forest products. There are techniques available that could make research evaluations more credible that just aren't being used. I think the problem has been that after you've gone through all the agonies and trials of trying to quantify research benefits and costs, you don't want to spend another year developing a sophisticated diffusion model to get incrementally better information.

ROBERT WESTGATE

Something that I've noticed in my containerized seedling study is the paucity of data available today. I had to estimate 11 variables in my study and there were only data on two of them readily available; the rest had to be estimated through various techniques which often leave a lot to be desired.

We have been talking about the diffusion of research results, or the diffusion of technology. I talked to a person in State and Private Forestry in Utah about prices of bare-root seedlings as compared with container seedlings. He told me that he didn't recommend container seedlings to people that he had advised, because they were about $4 per thousand more. He just didn't think that they should have to pay that much more for container seedlings. There is a lot more to reforestation than the price of seedlings. Now when you have people who don't even know what the price for seedlings really is or should be, you get into a lot of problems. I don't know how hard it is to get this kind of data or how much it would cost, but it just strikes me that before we worry about forecasting and things like that, we should worry about what's available today and what isn't.

ALLEN LUNDGREN

One of the areas where we seem to be most lacking in information is records of adoption of various kinds of practices, even records of activities carried out, such as the number of acres cut. These things are not readily available. You could get them but it's likely to be a costly operation. Sometimes the budget for research simply won't allow you to go out and collect all the information you need and you could spend the whole research budget on doing that alone. This is a real problem we face. In agriculture, there is an enormous data-gathering network that's producing information about the rates of adoption of corn varieties and other detailed data. For example, the number of acres planted, even down to the county level, and things like this. Those records are summarized and available but that isn't true in forestry.

BRUCE BARE

In calculating the rate of return study on research investments, when do you count the benefits? When research is adopted, or when the results of the adoption themselves are received? For example, if your research increases yields, but you don't harvest trees for 30 years, when do you count those benefits?

ROBERT WESTGATE

You count them pretty much from when they start. For example, I started counting container benefits when containers were actually being planted in a reforestation sense. Not in a research sense, trial planting and such, but actually being planted by industry or whoever plants them. In this case, it started in 1970. I consider that adoption, when it is actually being used.

BILL HYDE

You counted that because at that moment you got a change in cost. If you were addressing yield increases, you would count them 30 or 40 years later, whenever they occur.

HANS GREGERSEN

That's why, as we were saying before, almost by definition, it's impossible to get a very high rate of return. Can you imagine a 240 percent rate of return when you're getting benefits 30 years down the line?

BRUCE BARE

Then you don't end up with a return to research in that case. Instead, you end up with a joint rate of return on the research investment plus the cost of adoption. How do we interpret this?

HANS GREGERSEN

What the ag economists have faced is that there are different adoption costs and quite often they simply made assumptions about those costs. The common figure is 30 percent of research costs, or something similar.

JOHN FEDKIW

The adoption costs may not be fully chargable, because the cost of producing may be less. It's the incremental cost that must be counted. Perhaps the production may be cheaper per unit. Then the adoption is really a net saving, except for those things that occur which stop production for awhile, or lead to obsolescence of equipment before the full value has been realized from it.

BILL HYDE

A power backup roller is a wholly new item, so its whole cost is incremental. The seed that is put in the ground for a new seedling may just be a cost change.

SUMMARY

WORKSHOP SUMMARY

Christopher D. Risbrudt,
North Central Forest Experiment Station,
St. Paul, Minnesota

The formal evaluation of forestry research dates back at least to the Bailey and Spoehr report of 1929. Several reviews of forestry research needs have been made since, including the CRUSK report (Barnowe 1973), the report of the National Task Force of Basic Research in Forestry and Renewable Resources (1983), and the 1980-1990 National Program of Research for Forests and Associated Rangelands (USDA Forest Service 1982). Criteria for decision-making in research programs in forestry have also been described (USDA Forest Service 1981). However, evaluation in the sense of identifying the impacts of research-generated knowledge on the economy and society is much more recent. In agriculture, the Griliches study (1957) of the impacts of hybrid corn is generally recognized as the beginning of research evaluation in that field. In forestry, the Robinson study (1975) of technological change in the forest industries may be considered the beginning of research evaluation.

The boundaries of forestry research evaluation as a subfield of both forestry and economics (perhaps some would argue that evaluation is itself a field) have yet to be fully defined. It is an extremely young scientific endeavor, and the studies, both complete and just beginning, reported in this proceedings represent the majority of work done to date. Hence, these studies form the first outline, however hazy, of the type of information and methods that will be forthcoming.

As Allen Lundgren points out in his paper, the subfield of forestry research evaluation has yet to establish any traditions, scientific or otherwise. I hope and believe that this workshop represents the beginnings of such traditions, for it is through building on such bases that any scientific endeavor develops.

Research is now underway, or studies have been completed, for the evaluation of the returns to research in (1) forest products utilization, (2) forest harvesting, (3) forest fertilization, (4) timber management, (5) growth and yield modeling, (6) tree improvement, (7) reseacher effectiveness and productivity, (8) recreation, and (9) the role of research in industrial management decisions. Also, the first technology assessment of loblolly pine is under consideration, as is an evaluation of the use of forest survey information. Other studies not mentioned here are also in various stages of planning and consideration. These all are an indication of the vigor of this area of research.

Because this area of research is young, it offers many opportunities to extend our knowledge. Although several excellent studies have been completed, the base of *ex post* studies should continue to be expanded. While the results of *ex post* studies reveal the payoffs from past research rather than indicate the areas where future efforts should necessarily be made, they form an important base of knowledge for research management, and provide clues to the successful development of evaluation methods.

However, it is also important to develop *ex ante* methods of research evaluation. In this field of research, it is not always possible, nor often proper, to simply extend trends to project where research will generate the greatest desired impacts. *Ex post* methods are not always suitable, and *ex ante* methods must be developed, adapted, or adopted. The successful application of such new methods to alternative research programs will be most useful to research managers.

Forestry research evaluation appears to be following two lines of development. First, some studies are being done in the mold of those conducted by agricultural economists who have estimated the impacts of research on agricultural commodities. For forestry, this means evaluation of forest products utilization research. Timber management research also falls into this category, although no studies are yet complete. For beginning efforts in forestry research evaluation, this was the logical place to start. However, the nonmarket aspects of agricultural research have remained virtually untouched by evaluations. In forestry, a much larger portion of the research effort concerns nonmarket-valued outputs, such as recreation, watersheds, and wildlife. To claim to have examined all or even most of the research effort in forestry, these lines of scientific inquiry must also be evaluated. Hence, the second line of development in

forestry research evaluation is typified by the work at the College of Forestry at the University of Minnesota, which seeks to develop credible methods for evaluating recreation research. The knowledge gained can be applied to developing methods for evaluation of other lines of forestry research which have their impact primarily on nonmarket-valued outputs, such as water and wildlife.

An exciting development in research evaluation is the technology assessment pioneered by Burt Sundquist and his assistants, and discussed by him in this proceedings. This work develops evaluation to perhaps its broadest form, and its usefulness has received wide acclaim. An effort to apply this type of evaluation is now underway at Duke University.

The evaluation of forestry research is the study of the research process, from the work of individual scientists and projects and laboratories, through the dissemination process, to the identification and valuation of its impacts on society and the economy. As such, its results are of interest to a wide range of decisionmakers, including the doers of research, the funders, the disseminators, the administrators, and the users. This workshop represents a solid beginning of this promising and exciting line of "research on research."

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North Central Forest Experiment Station

General Technical Report **NC-105**

Fire Effects in Northeastern Forests: Oak

Cary Rouse



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Manuscript approved for publication November 6, 1985
1986

PREFACE

This is the second in a series of papers dealing with fire effects in northeastern forests. The 21-State region incorporates many diverse ecosystems—the northern hardwoods of New England, the boreal forests of Minnesota, the oak-hickory forests of Missouri, and fine hardwoods in the Central States. In spite of the fact that all forests have some things in common, each responds somewhat differently to fire. Although less is known about fire ecology in the Northeast than in any other region of the country, some information is scattered throughout the literature. The purpose of this series is to compile what we know today and make it readily available to managers. Each paper in the series will summarize the literature; detailed information on specific topics can be obtained from the accompanying references. When the series is complete in several years, the individual papers will be updated and republished as a single, bound volume. Other papers in the series to date include: aspen.

ACKNOWLEDGEMENT

I would like to thank Fred McCauley for his excellent artwork created for the cover.

FIRE EFFECTS IN NORTHEASTERN FORESTS: OAK

Cary Rouse, *Research Forester,*
East Lansing, Michigan

". . . almost every forest climax of North America displays a fire subclimax . . ." (7).

Fire is Important

Fire has played a major role in the forest ecosystems of the Northeastern and North Central United States (23). Although fire's role in destroying and renewing eastern hardwood forests has diminished greatly during this century, wildland fires, and their absence, can have a profound effect on both overstory and understory vegetation. Oaks, for instance, are commonly assumed to be favored over other hardwood species, by occasional fire. Our purpose here is to bring together some of the existing information about the effects of fire on some of the major upland oak species in eastern North America.

Origin of Existing Stands

Many upland oak stands of today originated under the severe conditions of human-caused intentional broadcast burning, destructive logging practices, and severe fires that consumed heavy slash. In some cases, the combination of these factors reduced the viability of previously dominant seeds of other species that remained in the duff.

MORTALITY

Heat

Fire can injure or kill any living tissue; the cambium and leaves of an oak tree are not exceptions. When living tissue reaches 147°F, it dies almost instantaneously (2). But the death of plant tissue is a function of both temperature and time. For example, a cambium layer exposed to 120°F for over an hour will die (2). To produce such temperatures at the cambium layer, there must be more heat or a longer heating time at outer bark surfaces.

Factors

Several factors determine direct fire-caused mortality in oak: season of year; bark characteristics, size, vigor, and form of tree; fire intensity; and stocking level.

Season and Bark

During the dormant season, trees are generally less susceptible to injury by fire because of their physiological state (6). In addition, ambient air temperature tends to be lower than during the growing season, necessitating higher energy release to raise the internal temperature of the tree to the lethal point (20). Bark characteristics are determined by the species and age of a tree. The easiest bark characteristic to measure is bark thickness although this is not always a true indicator of resistance to fire. For oaks, bark thickness decreases in the following order: chestnut, black, red, and white oak. Based on bark thickness alone, red oaks should be more resistant to damage than white oaks. This is not true in Missouri where the red oak group is much more susceptible to fire damage than the white oak group (22), but it may be accurate elsewhere. In addition to bark thickness, other differences among oak species such as bark configuration and chemical constituents contribute to fire resistence but have not been fully explained (35, 3, 20, 8, 30).

Size and Vigor

Larger trees are able to survive more intense fires than smaller trees (15, 28, 30) not only because they have thicker bark but also because they have a larger area of cambium that can continue to function if a portion is killed. Trees of low vigor do not sprout well and may not be able to heal as quickly as more vigorous trees (16). Intense summer burns can reduce the vigor of oak trees (5).

Form

The form of an oak tree is also a factor in determining severity of fire damage. If a tree is crooked or leaning, flames may be directly below the stem, increasing heat at the bark surface (28).

Fire Intensity and Stocking

Fire intensity is markedly different from fire to fire and even within a fire.[1] The greater the fire intensity the more energy is directed at the tree the greater the likelihood of death or injury (9). Scorch height can be used as a rough approximation of fire intensity (20).[2] Because stems in an overstocked stand tend to be smaller in diameter and less vigorous than those in an adequately stocked stand, they are more likely to be fire-damaged.

Other Damage

The loss due directly to a fire may be but a small percentage of the total damage of trees lost later to pathogens (1). Basal fire wounds provide a threshold for insects and decay that may degrade and eventually kill trees prematurely (20). The propensity of oaks to frost crack also increases due to injuries (14), including those from fire.

REPRODUCTION AND STAND ESTABLISHMENT

Oak regeneration and establishment can be divided into several categories including: (1) acorn production, (2) seedling establishment, and (3) sprouting.

Acorn Production

Although acorn production appears little affected by fire, a dying tree will often produce a massive seed crop (27). Acorns themselves can be killed by a fire before they have germinated because they have a high moisture content (29). The moisture inside the acorn can heat up and burst open the acorn.

Seedling Establishment

Seedling establishment depends upon sound acorns escaping predation, surviving overwintering conditions (for those in the red oak group), the successful penetration of the cotyledons through the leaf litter, and penetration of the roots to the

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[1]*To compare fires, we must know fire intensity (the product of the available fuel energy and the rate of spread) (4). The intensity of a flaming front can be determined from the flame length. Flame length, as well as rate of spread, can give an approximation of heat released. Rothermel and Deeming have given methods to estimate both rate of spread and flame length in the field without instruments (24).*

[2]*Simard, Albert J.; Baumgartner, David C. Predicting hardwood mortality following wildfires in the Lake States. Presented to: 89th Annual Meeting Michigan Academy of Science, Arts and Letters, March 22-23, 1985. Michigan State University. East Lansing, MI.*

mineral soil (13). These requirements are influenced by several factors including litter depth. Litter depth is readily reduced by fire. For example, an area that had been repeatedly burned then kept fire free for 10 years had twice as many oak seedlings as a comparable unburned area (3).

Roots

In northeastern hardwood forests, surface fires are most common (3). Aerial portions of trees may be injured or killed but roots are generally left viable (18, 11). Although root tissue is more susceptible to heat-induced injury than above-ground tree tissues (12), the insulating quality of the soil and the heat-release charateristics of most fires allow roots to remain viable.

Sprouting

Oak trees often resprout when top-killed by fire, thus re-establishing a stand. This ability is due in part to initial seedling morphology. Many oak seedlings develop an "S" shaped crook at the soil surface that allows dormant buds to be protected from the heat of a fire.[3] With repeated fires, these stems form "stools" (callus tissue filled with dormant buds) (17). The new sprouts grow vigorously, using the existing older root stock after the above-ground stem is killed. Numbers of sprouts are often increased by fires (25). Sprouts may be the most desirable form of reproduction (25). Many sprouts can rapidly attain the height needed (4.5 ft) to make them effective members of a regenerating stand (26). Southern red, post, and scarlet oaks produced more sprouts on annually and periodically burned areas than on unburned areas (33). Also, white oak sprouts were found to increase from 500 to 2,000 stems per acre after two spring burns of "moderate" to "high" intensity (35). Black and scarlet oaks sprouts also increased but not as dramatically as the white oaks.

Other Competition

Fire can reduce the stocking of other species relative to oak, thereby decreasing interspecies competition. For instance, in Rhode Island, scarlet, white, and black oak overstory trees accounted for 94 percent of the total basal area on repeatedly burned plots compared with only 53 percent on unburned plots (3).

Best Germination

The best oak acorn germination occurs on mineral soil under a light covering of leaves (25). Fire can help provide this condition by reducing excess litter. In addition to providing desirable seed bed conditions, fire can help induce more vigorous sprouting from older root stocks, which may produce a desirable form of reproduction.

ESTABLISHED STANDS

Secondary Effects

Fire can injure, kill, stimulate, or have no effect on the components of an established oak stand. Fire injury occurs in established oak trees when the cambium is killed. Such wounds provide a threshold for insects and diseases. Ambrosia beetles may begin to bore fire-damaged scarlet oak within 6 months after a fire.

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[3]*McQuilkin, Robert A. The possible role of fire in the oak regeneration process. Columbia, MO: North Central Forest Experiment Station; 1982. 29 p. Unpublished paper.*

It appears that the beetles prefer working in more severely damaged trees. In a New York study, 45 percent of fire-injured, but living oak trees became infected with fungi (31). These fungi, with one exception, appeared after fires, but were not present in undamaged trees. In another study, abundant fungi caused superficial decay of oak sapwood during the first summer after a fire. By the second season the fungi had migrated deeper into the sapwood; and by the third season, heartrot had developed (1). Insects attacked mainly in the first year after a fire; the total number of fungi peaked in the third year. Rot in lowland red oak develops up the bole of a damaged tree at an estimated 1.25 feet per decade (34). Oaks can minimize losses due to damaged cambium by rerouting the functions of fire-killed portions within weeks after a fire (10).

Estimating Damage

Estimating stem damage and subsequent mortality of fire-injured trees is difficult. Equations have been devised to predict mortality based on degree of basal scorch. For example, we may expect that 50 percent of post oak trees 5 inches in diameter at breast height (d.b.h.) will die if the scorch height reaches 5 feet during the growing season. During the dormant season, scorch height must reach 7 feet to cause the same amount of mortality. White, black, and scarlet oaks are not able to withstand as high a scorch height as post oak. In addition to scorch height, circumference scorched can aid in predicting fire-related mortality. Large white, black, northern red, and chestnut oaks can withstand bark scorch up to two-thirds of their circumferences (19).

No Effect

Often, no change in the growth of surviving trees is noticed after a fire. For example, in New Jersey on poor sites, diameter growth remained the same on basally fire wounded trees as on trees with no wounds (28). Also, in the southern Appalachian Mountains, Jemison reported that basal wounding of 8- to 20-inch-diameter vigorous white and black oaks did not affect diameter growth for 2 to 7 years after the fires (10).

Stimulation

In some instances, fire may stimulate the growth of oak trees, as reflected by incremental increases in height and/or diameter. Jemison discovered that if a wound on an 8- to 10-inch-d.b.h. white oak is less than 27 percent of its circumference, the tree grows faster the first year after a fire than before the fire.

SUMMARY

Fire in Oak

Many of today's oak stands have evolved as part of a community subjected to recurring fires (32). Recent management difficulties in establishing natural oak regeneration may be due, in part, to a changed forest floor brought about by an absence of fire. Existing forest floors on some oak sites provide a more favorable seed bed for more tolerant tree species but a poor seed bed for acorns. Controlled fire may play a critical role in the natural perpetuation of the upland oaks types. For instance, seedling establishment may be increased by burning due to a decrease in litter depth and exposure of mineral soil. Also, competition from other species might be reduced and the proportion of oaks in advanced reproduction might be increased with fire. And, after stand establishment, fire might be used to keep less desirable species from encroaching under oak.

Prediction Difficult

Fire is still undeveloped as a a silvicultural tool in upland oak management. The range of effects from fire to fire and even within a single fire is great, making predictions of effects difficult. The best available specific guidelines on fire application can be found in *A Guide for Prescribed Fire in Southern Forests* (21) and in handbook and manual supplements for specific national forests.

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Rouse, Cary. 105
Fire effects in northeastern forests: oak [redacted]. Gen. Tech. Rep. NC-[redacted] St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 7 p.

Effects of fire on the oak timber type are reviewed. Many oak stands of today originated under severe fire regimes. Fire can kill or injure oak trees. Factors determining direct injury or mortality from fire include: season of year; bark characteristics, size, vigor and form of tree; fire characteristics and stocking level.

KEY WORDS: Fire ecology, fire management, silviculture.



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North Central Forest Experiment Station

General Technical Report **NC-106**

Fire Effects in Northeastern Forests: Jack Pine

Cary Rouse



PREFACE

This is the third in a series of papers dealing with fire effects in northeastern forest. The 21-State region incorporates many diverse ecosystems—the northern hardwoods of New England, the boreal forests of Minnesota, the oak-hickory forests of Missouri, and fine hardwoods in the Central States. In spite of the fact that all forests have some things in common, each responds somewhat differently to fire. Although less is known about fire ecology in the Northeast than in any other region of the country, some information is scattered throughout the literature. The purpose of this series is to compile what we know today and make it readily available to managers. Each paper in the series will summarize the literature; detailed information on specific topics can be obtained from the accompanying references. When the series is complete in several years, the individual papers will be updated and republished in a single, bound volume. Other papers available through the North Central Forest Experiment Station in the series to date include: aspen, oak.

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I would like to thank Fred McCauley for his excellent artwork created for the cover design.

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FIRE EFFECTS IN NORTHEASTERN FORESTS: JACK PINE

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" . . . almost every forest climax of North America displays a fire subclimax . . ." (17).

Fire is Important

Fire has played a major role in the forest ecosystems of North America (28). Fire in the jack pine forest type has long intrigued many researchers (from Ellis in 1911 (14) to Abrams in 1984 (1)). Unfortunately, much of the literature lacks the prefire vegetation and fire behavior documentation necessary for predicting fire effects.[1] In this report, we bring together existing information about the effects of fire onthe jack pine forest type in eastern North America and suggest silivicultural uses of prescribed fire in this type.

HISTORY

Origin of Existing Stands

Many jack pine stands of today originated after devastating wildfires (4, 10). These fires, caused either by humans or lightning, burned until they met an obstacle (such as rivers, lakes, or changes in cover type) or until weather changes made fuels less flammable. Plant communities in repeatedly burned areas might evolve to become more flammable to maintain themselves (27). This hypothesis certainly seems true of jack pine communities. Debris breaks down slowly in jack pine, and woody material that falls to the ground remains as fuel available for fire spread for several years. When a stand begins to break up, fuel arrangement and amount enhance the likelihood of a severe fire (20). The probability of a lighning-caused ignition increases until fire does occur. Fuels are reduced with a killing fire, and the stand is often regenerated on favorable seedbeds by seeds released from serotinous cones. Fire in jack pine clearly influences nutrient cycles and energy pathways, thus helping to maintain diversity, productivity, and long-term stability (21). For example, 1 year after the Mack Lake fire, water holding capacity, organic carbon, and cation exchange capacity all remained above pre-fire levels.[2]

Natural Fire Cycle

Fire intervals, the time between fires on the same area (26), have been calculated for jack pine in various locations. In the Boundary Waters Canoe Area of Minnesota, fires burned over the same area an average of every 6.1 years between 1727 and 1972 (21). Before settlement (1727-1868), the average fire interval in this area was 4.3 years with 21 to 28 years between major fire years (21). Eighty-four percent of the 532,000-acre land area burned during these major fire

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[1]*To compare fires readily, managers must know the fireline intensity (the product of energy from fuel consumed and the rate of spread expressed in BTU/second/foot) (9). The intensity of a flaming front can be estimated from the actual flame length. The flame length as well as the rate of spread can also approximate heat released. Methods have been devised to estimate both rate of spread and flame length in the field without instruments (29).*

[2]*Cleland, David T. Fire effects summary for all quartzitic sands. Forest Service Memo, June 27, 1984.*

years. Heinselman (19) believes that jack pine barrens on sandy plains experienced light, surface fires as often as once every 15 to 30 years throughout jack pine's range. In lower Michigan, Simard and Blank (32) found a 25-year average fire interval between 1830 and 1980. Before settlement (1830-1849) the average interval was 27 years and dropped to 10 years during settlement (1850-1909). With initial suppression efforts, the period lengthened to 18 years and is now about 30 years. Major fires now occur an average of once every 28 years.

FIRE EFFECTS

Factors

Several factors determine direct fire-caused mortality in jack pine: season; bark characteristics, vigor, form, and size of tree; and specific fire characteristics.

Lethal Temperature

Fire can injure or kill any living tissue, including the cambium and needles of a jack pine tree. When living tissue reaches 147°F (64°C), it dies almost instantaneously (7). This is a good general figure, but death of plant tissue is a function of temperature and time, commonly called residence time.

Season

During the winter, most trees are generally less susceptible to injury because they are dormant (15). In addition, ambient air temperature is lower than at other times of the year, meaning that fire must be more intense to raise the internal temperature of the tree to the lethal point than during other seasons (7).

Bark

Bark insulates and protects the tree's cambium. Differences in bark thickness and thermal conductivity result in differences in the amount of protection the living portion of the tree has from a fire. Bark characteristics are determined by the age of a tree and its growth characteristics. The easiest characteristic to measure is bark thickness. Clearly, the older the tree, the thicker the bark. Jack pine bark is not very thick at any age, but it is less dense and provides more insulation than some hardwood bark.

Form

The form of the tree is also important in determining the extent of damage. If a tree is crooked or leaning, the flame can be directly below the stem, concentrating heat there (34).

Tree Diameter

The same temperature directed at similar-size areas on a large tree and a small tree would usually harm the large tree less than the small one (24, 34). Large trees generally have thicker bark than small trees and a larger area of cambium that can continue to function if a portion is killed.

Fire Behavior

Fire characteristics can differ from fire to fire and even within a fire. Fire behavior is dependent upon several factors, most importantly, the fuel characteristics of the area burned and the fire weather (11). Byram's (9) fire intensity measures fire behavior in terms of heat released per unit time on a foot wide portion of fire line. The greater the fire intensity the more energy is directed at the tree and the higher the probability of injury.

REPRODUCTION AND STAND ESTABLISHMENT

Jack pine regeneration and establishment can be divided into three steps: (1) seed production and dissemination; (2) seedling germination; and (3) seedling survival and growth. Fire can be a factor in each step.

Seed Production and Dissemination

Jack pine trees can produce viable seed when they are only 3 to 5 years old (11), although cone production peaks around 40 to 60 years of age (27). Seeds can remain on a tree for years (2). Fifty percent of 20-year-old seeds may be able to germinate (11). Fire doesn't influence the actual seed production except that fire-stress can cause a jack pine to produce more seeds than without stress (33).

Most jack pine seeds are formed in serotinous cones (18). The serotinous cones are sealed with a resin that melts, liberating the seeds, at 120° to 140°F (49 to 60°C) (27). In jack pine's natural range, these high temperatures can usually only be reached by adding heat to existing air temperature, except on sandy soils where temperatures can reach 170°F at the surface, hot enough to open the cones. Therefore, serotinous cones are an adaptation to fire (22). A "moderately hot" fire can produce enough heat to release the seeds from serotinous cones in the crowns of standing trees (27). If the cones themselves are burned, however, the seed will be destroyed (10, 27). Only in the southern portion of its range does jack pine produce nonserotinous cones (6).

Burning Slash Unsuccessful

Jack pine slash (activity fuels) with cones remaining after a clearcut has been burned in an attempt to prepare a seedbed and liberate seeds in one activity (5, 10, 13). This has not proved very successful probably because fires were not able to consume enough fuel to prepare the site. Even if the fires had been able to prepare the ground, the seeds would probably have been incinerated (10, 27).

Seedling Germination

Once seeds have been released, they germinate best on mineral soil or soil with less than 0.2 inch of organic matter (27). The organic soil layer can be reduced with fire. If a seed source is available, seeds will often germinate soon after the fire. However, seeds are vulnerable to heat and dessication on blackened, dry organic soils and may not germinate or, if germinated, may die (11).

Seedbed

To ensure a good seedbed, slash remaining from a harvest must be reduced because it provides too much shade (25). Slash can be reduced with fire. Some shade, though, appears to favor germination. Standing dead jack pine can enhance establishment of jack pine by providing a slight amount of shade (27).[2] It appears that light shade aids in the regeneration of jack pine on sandy sites by allowing available moisture to be retained longer (2, 6, 27).

Growth and Survival

Once germinated, seedlings require full sunlight (6) and release from competing vegetation. This can be achieved, temporarily, by burning before jack pine establishment (27, 11). In addition to controlling competition, fire can also help protect

jack pine from pests, namely damping-off, Scleroderris canker, and dwarf mistletoe (11). In addition, newly created slash often encourages populations of *ips* beetle (6). This beetle can be checked by burning the slash.

Competition can be Slowed

After the overstory is removed, competition from sedges can be severe enough to prevent jack pine from becoming established Slowed on poor sandy sites in northern lower Michigan. Within 2 years of the removal of the canopy, sedges can fully occupy a site to the exclusion of almost all other vegetation, including jack pine.[3] Fire can slow this process, but only if used before or immediately after removing the overstory. The key to maintaining these areas in jack pine is timing. Jack pine must be established, either naturally or artificially, immediately after removing the canopy.

Rain Necessary

Even with the best of site preparation and release, jack pine establishment and growth, especially on sandy soils, is "heavily dependent upon a capricious growing season rainfall pattern" (5) because jack pine sites can experience drought conditions just 6 years after a 1/2 in. rain.[4]

Fire in Existing Stands

Fire can easily injure or kill an established jack pine stand (6). Jack pine foliage is highly combustible and burns readily when crowns are close to the ground (36). Few trees survive a crown fire. Young to "semi-mature" stands are more susceptible to crown fires than are older stands whose crowns are often thinner and higher (35). Benzie (6) recommends that fire not be used for any purpose in immature stands.

SUMMARY AND MANAGEMENT IMPLICATIONS

Stand Establishment

The best use of fire in the jack pine type is for site preparation in the establishment of a new stand. Fire can provide an economical alternative to mechanical site preparation. Fire can aid in regenerating a stand by preparing an adequate seedbed and sanitizing the site. Fire in an established stand, except at low intensity, is detrimental. Although past wildfires produced many of the jack pine stands of today, there is no guarantee that jack pine will become established after a fire (5). Although Buckman thought, in 1964 (8), that successful regeneration techniques using fire would soon emerge, today there is still no guaranteed method to produce an adequately stocked natural stand with fire. To be able to use fire for vegetative manipulation and to predict its effects, managers must know the following: prefire species composition and dominance, extent of buried seed pool, adequacy of adjacent seed sources, soils information, actual fire intensity and past disturbance history.[4] Although this information has not been recorded in the past, such information would allow managers to compare and refine burning techniques needed to meet specific management objectives.

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[3]*Abrams, Marc D. Early plant succession on clearcut and burned jack pine sites in northern lower Michigan. East Lansing, MI: Michigan State University; 1982. 191 p. Ph.D. dissertation.*

[4]*Ibid.*

Seedbed Preparation

The consensus has been that to get an adequate seed catch, duff must be severely reduced (12, 16). It has been suggested that the best time to burn is 1 month after harvest in the spring (3, 6, 30). But this is the time of most severe fire weather and one day's successful burn could be the next day's escaped fire.[5]

Stand Rejuvenation

Many acres of unmerchantable jack pine in the Northeast are approaching decadence. Van Wagner (5) suggested that "if a forest is not going to be completely regulated by logging and silviculture, then presumably natural regulating forces must be allowed some free rein . . ." In the case of jack pine, lack of cutting will result in decadent stands with much fuel—prime candidates for major conflagrations. Kayll (23) proposes a drastic solution. He recommends that "if a mature forest cannot be harvested then fire may be one way to establish a valuable new forest in its place." He suggests burning under controlled conditions to avoid "silvicultural slums." Many jack pine stands in the Northeast are becoming such slums.

Obstacles

The largest physical obstacle to rapid expansion of prescribed burning in the jack pine region is the limited number of days when fire weather is appropriate to burn (8). For example, during the spring in lower Michigan, fire weather appropriate for prescribed burning rarely lasts more than 1 day (31). In addition to this physical limitation are attitudinal obstacles: remembrance of recent and historic destructive fires such as the Mack Lake fire in Michigan (31); organizational bias—towards control rather than fire use; and the widespread acceptance of other methods—chemical, mechanical, and silvicultural techniques (8). Despite these limitations, some burning in the jack pine type is occurring in Minnesota for site preparation and in Michigan for Kirtland warbler habitat management.

Prediction Is Difficult

Research concerning fire's place and use in jack pine has provided much information but no universal answers. Results of burning on one area are not repeatable on another. As more site-specific information is collected, managers can gain confidence in it and burning will be viewed as an accepted management practice (especially for site preparation).

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The jack pine ecosystem has evolved through fire. Jack pine, although easily killed by fire, has developed serotinous cones that depend upon high heat to open and release the seeds. Without a fire to enable the cones to open, jack pine would be replaced by another species.

Prescribed fire can be an economical management tool for site preparation in either a natural or artificial regeneration system.

KEY WORDS: *Pinus banksiana*, fire ecology, silviculture.

1966-86



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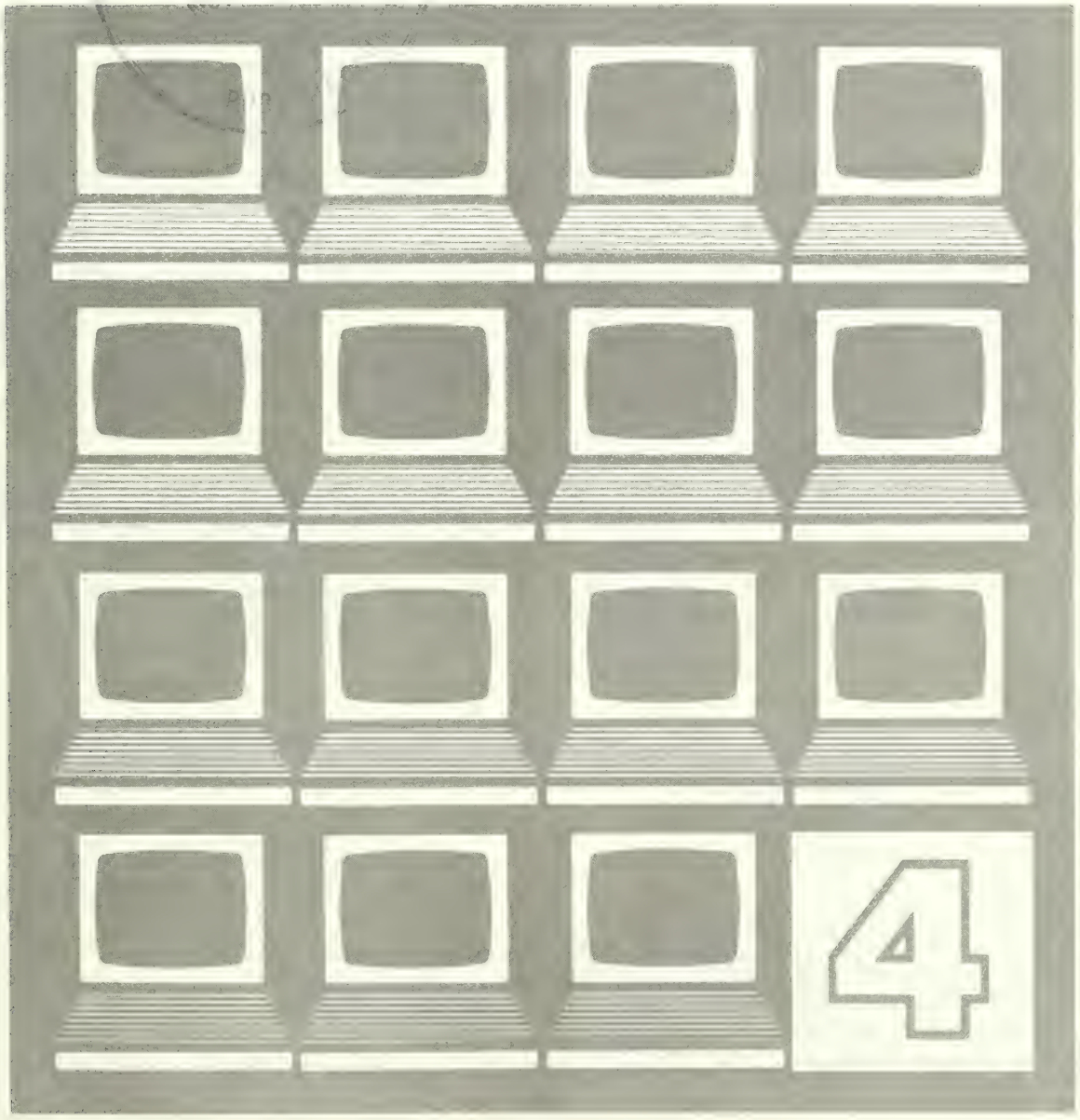
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General Technical Report **NC-107**

The Microcomputer Scientific Software Series 4

Testing Prediction Accuracy

Harold M. Rauscher



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1986

THE MICROCOMPUTER SCIENTIFIC SOFTWARE SERIES 4: TESTING PREDICTION ACCURACY

H. Michael Rauscher, *Research Forester*,
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GENERAL INFORMATION

Identification

Name of Program:	ATEST
Name of Author:	H. Michael Rauscher
Location:	North Central Forest Experiment Station 1831 Highway 169 East Grand Rapids, MN 55744
Language:	MICROSOFT BASIC[1]
Operating System:	MSDOS
Computer:	IBM PC/XT[1]

This manual is designed as both a user's and programmer's guide to program ATEST. ATEST will be described in enough detail to allow a knowledgeable user to implement improvements and extensions. The complete BASIC language source code for this program is included in appendix A.

Objectives

In this paper I have two objectives:

(a) Provide a computer program for testing the accuracy of prediction models.

(b) Provide users with enough program details to allow implementation of extensions and refinements.

[1]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

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APPLICATION

General

Models are constantly being used by forest managers and researchers for prediction. Most users of predictors fail to independently determine the predictive power (accuracy) of the models they are using for their specific applications. Mosteller and Tukey (1977) summarize the statistician's point of view:

"Users have often been disappointed by procedures, such as multiple regressions, that 'forecast' quite well for the data on which they were built. When tried on fresh data, the predictive power of these procedures fell dismally."

The forestry community, by and large, does not know what degree of uncertainty is reasonable for a given application nor have we established the maximum uncertainty levels that should lead us to reject a prediction model.

One of the reasons for this deplorable situation is the lack of discussion in the scientific literature on the philosophy and testing procedures for accuracy. The paper by Reynolds (1984) redresses this deficiency. A second reason is the lack of computer tools to make accuracy testing of prediction systems easily possible. Program ATEST has been developed to make available a simple computer software tool that can be used to determine the accuracy of predictions.

Operating Instructions

This section of the manual contains two examples to explain how program ATEST can be used to assess prediction uncertainty.

Example #1

The first example deals with determining the accuracy of cruise data. True and predicted volumes from a hypothetical timber cruise have been artificially generated:

Observation number	Mill scale	Cruiser
	Cords/ac	
1	35	33
2	18	19
3	43	44
4	15	16
5	28	27
6	32	30
7	19	18
8	24	26
9	33	30
10	38	33

Let us choose the mill scale as the observed values and the cruisers' data as the predicted values. The program advises the user to let Y represent the observed (standard) values and X represent the predicted (competitor) values. The user is then asked to enter the units of measure of these values and the number of <Y, X> pairs of data to be entered. The program queries for each data pair until they are all entered. The program next requests whether the user wants to review the data for accuracy. The data pairs are displayed 10 points at a time and the user can edit any or all points in each display segment.

The program then computes the differences between the observed and predicted values ($D_i = Y_i - X_i$, i = 1 to n). The program also computes the percentage errors between the observed and the predicted values (D_i (%) = 100 (D_i/Y_i), i = 1 to n). Both sets of errors are tested against the hypothesis that the differences (D_i) follow a normal distribution whose mean equals the mean of the sample data set and whose variance equals the variance of the sample data set. The probability plot correlation coefficient (Filliben 1975) is computed for both the raw errors and the errors in percent. Based on the sample size and the value of the correlation coefficient, the user is asked to refer to the table in appendix B or Filliben (1975, table 1) to decide if there is evidence to contradict the hypothesis of normality. In this example, the correlation coefficient for the raw data is 0.9699. Looking at appendix B where n = 10, we see that 0.9699 is well above the 0.05 critical level and lies between the 0.25 and 0.50 critical levels. We can conclude that we have no reason to reject the hypothesis of normality and can respond negatively to the question in the program. In this example the correlation coefficient for the percent errors is 0.9737 and likewise fails to produce evidence to reject the assumption of normality.

The user is then asked to enter the desired two-sided probability level, alpha, which is often 0.05 or 0.01. Finally, in order to compute the length of the tolerance interval, a value for K (equation 10 this paper) must be entered from appendix C or Eisenhart *et al.* (1947, table 2.1). For this example, with N = 10, gamma = 0.95, and P = 0.95 (alpha = 0.05), K = 3.379.

The program continues to process until the output is reported as:

RESULTS FOR ERRORS IN CDS/AC:
(THE TWO-SIDED PROBABILITY LEVEL (ALPHA) IS: 0.05)

BIAS	CONFIDENCE INTERVAL	PREDICTION INTERVAL	TOLERANCE INTERVAL	S	N
0.9	+/−1.56	+/−5.18	+/−7.37	2.18	10

RESULTS FOR ERRORS IN PERCENT:
(THE TWO-SIDED PROBABILITY LEVEL (ALPHA) IS: 0.05)

BIAS	CONFIDENCE INTERVAL	PREDICTION INTERVAL	TOLERANCE INTERVAL	S	N
2.0	+/−5.21	+/−17.29	+/−24.60	7.28	10

The average difference between the mill scale and the Cruiser's estimates ($Y_i - X_i$) is 0.9 CDS/AC. Notice that this indicates an *underestimation* of the true values. Is this bias significantly different from zero? The answer is no because the 95-percent confidence interval about the bias (−0.66 to +2.46) includes zero. Based on past performance, we may be

interested in obtaining an interval to include the error in a future prediction. The *confidence interval* assesses uncertainty based on the sample at hand and almost certainly overestimates the performance of the predictor (Mosteller and Tukey 1977). The real question relates to the uncertainty associated with future predictions, so we must use either the prediction or the tolerance intervals. Using the *prediction interval*, we can be 95 percent confident that in a single future prediction the error will be between −4.28 and +6.08 CDS/AC (0.9 +/− 5.18). The estimate is likely to vary between a 4.28 CDS/AC overprediction to a 6.08 CDS/AC underprediction.

If we want to provide limits to contain future errors in the long run, then we must use a *tolerance interval*. In this example we are 95-percent confident that at least 95 percent of the population of errors fall between −6.47 and 8.27 CDS/AC (0.9 +/− 7.37). Thus the magnitude of the long-term errors should be no more than about 7.37 CDS/AC.

The conclusions reached concerning the accuracy of a system to predict future events apply *only* if the prediction system is used in the same way as it was used for assessing the accuracy in the first place. Making changes in the prediction system or applying it to a different population invalidates the assessed levels of accuracy (Reynolds 1984).

Errors can also be evaluated as percentage differences from the observed or standard values (D_i (%) = 100 (D_i/Y_i)). In this case the bias is + 2.0 percent, which is not significantly different from zero at the 95 percent probability level because the confidence interval contains zero (−3.21 to 7.21). We can be 95-percent confident that the error of a single future prediction will lie between −15.29 and 17.29 percent of the mill scale value (0.2 +/− 17.29). Finally, we can be 95 percent confident that 95 percent of the errors over the long term will fall between −22.6 and 26.6 percent of the mill scale values. The magnitude of the long-term errors should be no more than about 24.6 percent.

Example #2

The second example illustrates how to use ATEST to determine the accuracy of a basal area growth model. Buckman (1962) developed a basal area growth model for red pine based on 235 permanent sample plots in 14 stands. His model is:

$$BAG = 1.6889 + .041066 * BA - .00016303 * BA^2 - .076958 * A + .00022741 * A^2 + .06441 * SI \quad (1)$$

where:

BAG = periodic net annual basal area growth in ft^2/acre

BA = basal area in ft^2/acre

A = age in years

SI = site index in feet at index age of 50 years

Since 1962 these same plots have been maintained and measured four additional times in 5-year increments. Every 5 years from 1959 to 1979, three replications of five density regimes were marked and cut to one of the desired nominal densities of 60, 80, 100, 120, and 140 ft^2 basal area per acre. From research records, I obtained the "true" basal area growth increments (Y) for the periods:

1. 1959-1964;
2. 1964-1969;
3. 1969-1974; and
4. 1974-1979.

I used model (1) to predict growth based on site index, age, and beginning basal area to generate the "competitor" (X) values. For the sake of brevity, I have presented the input values for only the first growth period (table 1).

The results show that the bias, (table 2), is significantly different from zero at the 95-percent probability level only for the final period, 1974-1979. Because the bias is negative, the predictor overestimates the observed values. The prediction model provides unbiased estimates for 15 years of basal

Table 1.—*True and competitor values of basal area growth for period 1: 1959–1964*

Site[1] index (feet)	1959[2] Starting basal area	1959–1964[3] True basal area growth	1959–1964 Predicted basal area growth
	ft^2/ac	-------- ft^2/ac/5 yrs --------	
47	60.0	8.1	6.6
50	59.0	7.3	7.6
48	59.8	6.5	6.9
48	79.2	9.2	9.7
49	80.1	8.6	9.1
48	79.8	8.2	8.7
47	99.5	11.8	9.5
48	100.5	8.8	9.8
51	100.4	11.5	10.8
49	120.0	10.8	10.5
48	119.9	10.7	10.2
49	119.6	8.6	10.5
51	140.3	11.9	10.9
48	141.0	10.9	9.9
51	140.0	8.6	10.9

[1]Base age 50.
[2]Stand was 95 years old in 1959.
[3]Average of three 1/5-acre plots.

Table 2.—*Results from program ATEST for example #2*

A. RESULTS FOR ERRORS IN FT²/AC/5 YRS: (THE TWO-SIDED PROBABILITY LEVEL (ALPHA) IS: 0.05)

TIME PERIOD	BIAS	CONFIDENCE INTERVAL	PREDICTION INTERVAL	TOLERANCE INTERVAL	S	N
1959–1964	0.06	+/−0.68	+/−2.73	+/−3.63	1.23	15
1964–1969	−0.05	+/−0.88	+/−3.51	+/−4.70	1.59	15
1969–1974	0.17	+/−1.07	+/−4.28	+/−5.70	1.93	15
1974–1979	0.72	+/−0.65	+/−2.60	+/−3.46	1.17	15

B. RESULTS FOR ERRORS IN PERCENT: (THE TWO-SIDED PROBABILITY LEVEL (ALPHA) IS: 0.05)

TIME PERIOD	BIAS	CONFIDENCE INTERVAL	PREDICTION INTERVAL	TOLERANCE INTERVAL	S	N
1959–1964	−0.52	+/−7.29	+/−29.18	+/−38.90	13.17	15
1964–1969	−2.37	+/−11.21	+/−44.84	+/−59.79	20.24	15
1969–1974	−1.70	+/−14.23	+/−56.94	+/−75.92	25.70	15
1974–1979	−10.10	+/−17.97	+/−71.87	+/−95.83	32.44	15

area growth on the plots used originally for calibration. After year 15, estimates overpredict by about 0.72 ft²/acre, which is about 10 percent of the observed basal area.

The magnitude of the long-term errors steadily increases with time except for the 1974-1979 period (see column marked TOLERANCE INTERVAL). This trend indicates that, in general, the precision of the predicted estimates decreases as the number of years from the original measurements increases. This is not surprising. We can be 95-percent confident that 95 percent of the errors fall within 3.6 – 5.7 ft²/acre when using model (1) to predict 5-year basal area growth up to 20 years past the point where these plots were used to calibrate the model. Notice that most of the errors will fall between 39 percent and 96 percent of the observed values depending upon the 5-year interval selected.

PROCEDURES AND REQUIREMENTS

System Characteristics

Program ATEST is written in Microsoft BASIC-Crunning under MSDOS on an IBM-PC microcomputer system. No machine-dependent statements have been used. The program takes approximately 7 kilobytes of random access memory (RAM) for storage. Program ATEST is written so that the required input data are generated by the user through the keyboard. This method increases universality. Users who desire data input from disk files must write a simple subroutine to enter it from the format in which the data is stored.

Program Availability

ATEST is distributed by FORS, the Forest Resources Systems Institute, a non-profit organization for forestry computer support, at a nominal price to cover disk, postage, and handling. For further information on ordering a machine-readable copy, write or call:

The Forest Resources Systems Institute
Courtview Towers, Suite 24
201 North Pine Street
Florence, Alabama 35630
(205) 767-0250

Statistical Background

The problem is to assess the accuracy of a predictor. The prediction system may be the best estimates of experts, it may be a regression equation, or it may be a complex simulation model. For this problem, the form of the prediction system is irrelevant as long as the predicted and observed values estimate the same thing. Given a prediction system, the only way to evaluate its accuracy safely is to test it against a set of data different from those used to develop it in the first place (Mosteller and Tukey 1977). In statistical terms, appraising prediction accuracy requires cross-validation. Simple cross-validation tests the predictor against data different from those used to fit the numerical coefficients of the model form. Double cross-validation tests the predictor against data different from those used to choose the model form as well as its coefficients. Setting aside a portion of the data to test the model against is simple cross-validation. Gathering a fresh and independent set of data to conduct the accuracy test is double cross-validation (Mosteller and Tukey 1977).

In the past, the error ($D_i = Y_i - X_i$, or $D_i\,(\%) = 100\ D_i/Y_i$ where i = 1 to n) between observed (Y_i) and predicted (X_i) values has been evaluated in a variety of ways. The errors have been presented in a histogram or displayed in tabular form as in Gevorkiantz and Olson (1955, page 15). Others have recognized that prediction errors are composed of two components. The first component, bias, is the average error between predicted and observed values. Precision, the second component, refers to the clustering of sample values about their own average. The following estimators have been used to predict the degree of bias in the errors:

$\overline{D}$ average of the set of Di (1)

$|\overline{D}|$ average of the absolute value of Di (2)

The following estimators have been used to predict the degree of bias or precision of the errors:

ΣD_i sum of the set of D_i, i = 1 to n (3)

ΣD_i^2 sum of the set of D_i^2, i = 1 to n (4)

$\Sigma|D_i|$ sum of the set of absolute values of D_i,

$$i = 1 \text{ to } n \tag{5}$$

S(D) standard deviation of the set of D_i,

$$i = 1 \text{ to } n \tag{6}$$

S_D standard error of the mean, $\overline{D}$ (7)

Freese (1960) took the prediction of accuracy a step further. He proposed a statistical procedure to determine whether a prediction system attains the level of accuracy required by its user. Unfortunately, Freese (1960) failed to explicitly state the basic underlying assumptions so that users were unaware when these were violated (Reynolds 1984). Freese adopted the hypothesis testing philosophy that is appropriate when the question is whether or not a prediction system meets a specified accuracy requirement. More generally, we are interested in determining the magnitude (bias) and the precision of the prediction errors, which is appropriately addressed using the statistical estimation philosophical approach (Reynolds 1984).

If the set of D_i's is normally distributed, then a confidence interval can be computed directly based on the student's t-statistic.

$$\overline{D} \pm S\left[t_{1-\alpha/2}(n-1)\right]/\sqrt{n} \tag{8}$$

where:

$$\overline{D} = \sum_{i=1}^{n} D_i/n$$

S = Standard Deviation

$$= \sqrt{\frac{\sum_{i=1}^{n} (Di - \overline{D})^2}{n-1}}$$

$t_{1-\alpha/2}(n-1)$ = the $1-\alpha/2$ quartile of the t-distribution with $n-1$ degrees of freedom

n = number of observations

To compare accuracy of predictions on a relative basis (without reference to units), it is desirable to compute the errors in percent of the observed values. Unfortunately, if the errors in absolute terms are normally distributed, the percent errors may not be and vice versa (Reynolds 1984). When the normality assumption does not hold, (8) cannot be used without distorting of the alpha level of the t-test.

The jackknife procedure allows estimation of an approximate confidence interval without assuming normality. We proceed as follows. We check to ensure that the sample is at least unimodal. Because the mean is sensitive to non-normality, we choose the 10-percent trimmed mean (disregarding the upper and lower 10 percent of the observations) as a more robust location estimator (Mosteller and Tukey 1977). We resort to the jackknife procedure to calculate an estimate of the standard deviation of the errors (see Mosteller and Tukey 1977, pages 135-141, and Sokal and Rohlf 1981, pages 795-799). The jackknife pseudo-values have been shown to be "asymptotically distributed as a student's t with n-1 degrees of freedom as n approaches infinity" (Gray and Schucany 1972). Therefore, using the trimmed mean as an estimate of $\overline{D}$ and the jackknifed sample standard deviation as an estimate of S, we can compute the confidence interval as in (8).

The *confidence interval* is an indication of uncertainty based on the current sample and can be expected to overestimate the performance of the predictor (Mosteller and Tukey 1977). We are more often interested in the uncertainty associated with making future predictions.

A *prediction interval* is used to calculate the probability that k future values of D_i will fall within its range. Program ATEST assumes K = 1 and thus reports the range that a single future value of D_i should fall within given a specified probability level. Because the standard deviation (S) and the number of observations (n) are also reported, it is a simple matter for the user to compute the general case (where $K > 1$).

$$\overline{D} \pm \sqrt{1/n + 1/k}\; S\; t_{1-\alpha/2}\,(n-1) \tag{9}$$

where:

K = number of future estimates to be made.

If we want to provide limits to contain a specified proportion of the distribution D_i over the long term, we need to construct a *tolerance limit* (Reynolds 1984). A tolerance limit to contain at least a proportion P of the distribution of D_i is of the form:

$$\overline{D} \pm K\,(\gamma, n, P)\,S \tag{10}$$

where:

K = table value, appendix C (Eisenhart *et al.* 1947). The tolerance interval provides the range that over the long run will contain P percent of the distribution of D_i's with probability of γ.

To test for normality where location and scale are unspecified, we used the normal probability plot correlation coefficient (Filliben 1975). This test is conceptually and computationally simple and compares favorably with competing tests of the composite hypothesis of normality.

Warning! The prediction and tolerance intervals are very sensitive to non-normality. Nonparametric prediction intervals can be used, but these are not very satisfactory for small n (Reynolds, personal communication). The use of the trimmed mean and the jackknifed variance should provide a more robust confidence and prediction interval. Alternately, some type of data transformation could be used to achieve approximate normality (Mosteller and Tukey 1977).

PROGRAM CODE DOCUMENTATION

The initialization section of the program (lines 100-250) requests that the user enter the units of measure, the number of [Y,X] pairs, and the [Y,X] pairs themselves (fig. 1). The differences are computed both in raw units and in percent (line 240) and set into arrays DA(•) and DR(•), respectively. The user is given the chance to review and correct the data entry (lines 20000-20220). These two arrays are then sorted into ascending order (lines 10000-10230) by an in-place Shell-Metzner sorting algorithm.

Each array, in turn, is placed into the temporary array TMP(•) (lines 290-390) and tested for the composite hypothesis of normality (lines 11000-11360). The program reports the computed correlation coefficient in both raw and percent units and asks the user to decide whether there is enough evidence to contradict the assumption of normality (lines 400-530).

Based on whether the differences are normally distributed or not, results are computed by code (lines 12000-12160) or code (lines 13000-13300), respectively. The t-table value is computed (lines 14000-15240) based on an algorithm reported by Shammas (1984).

Finally, results are displayed (lines 680-870) and the user is asked if another problem is to be solved. If not, the program ends.

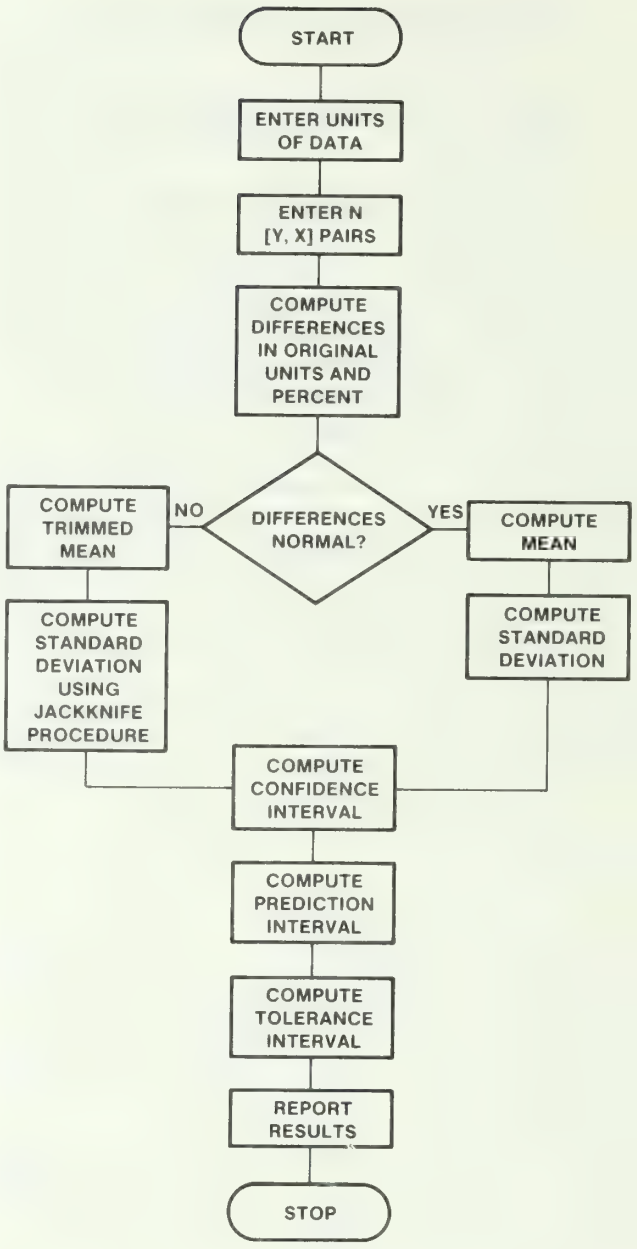


Figure 1.—*Flowchart of the logical blocks of program ATEST.*

APPENDIX A. COMPUTER SOURCE CODE FOR PROGRAM ATEST

```
100 REM  ************************************************************
110 REM  **    PROGRAM TO TEST ACCURACY
120 REM  **    VERSION :  2/12/85
130 REM  ************************************************************
140 CLS
142 CLEAR
145 PRINT"PROGRAM TO COMPUTE THE ACCURACY OF PREDICTIONS."
146 PRINT:PRINT
150 PRINT"LET Y REPRESENT THE STANDARD AND X REPRESENT THE COMPETITOR."
160 PRINT
170 PRINT"ENTER UNITS OF MEASURE OF THE DATA --> ";: INPUT UNITS$
180 PRINT:PRINT
190 PRINT"HOW MANY Y,X PAIRS WILL YOU ENTER --> ";: INPUT ROWS
200 DIM DA(ROWS),DR(ROWS),TMP(ROWS),MI(ROWS),Y(ROWS),X(ROWS)
210 FOR I=1 TO ROWS
220 PRINT
230 PRINT"PAIR NUMBER = ";I;"     ENTER [Y,X] --> ";: INPUT Y(I),X(I)
240 DA(I)=Y(I)-X(I): DR(I)=100*(DA(I)/Y(I))
250 NEXT I
255 GOSUB 20000:' CHECK DATA FOR CORRECT ENTRY
260 REM   SORT THE ERROR ARRAYS INTO ASCENDING ORDER
270 ITAG$="DA": GOSUB 10000
280 ITAG$="DR": GOSUB 10000
290 REM  FILL IN THE TEMPORARY ARRAY AND TEST FOR NORMALITY IN EACH CASE
300 FOR I=1 TO ROWS
310 TMP(I)=DA(I)
320 NEXT I
330 GOSUB 11000
340 DARHO=RHO
350 FOR I=1 TO ROWS
360 TMP(I)=DR(I)
370 NEXT I
380 GOSUB 11000
390 DRRHO=RHO
400 REM  DISPLAY RESULTS TO USER AND ASK FOR SIGNIFICANCE DETERMINATION
410 CLS
420 PRINT"THE NORMALITY TEST HAS BEEN COMPLETED FOR THE ABSOLUTE AND"
430 PRINT"     AND RELATIVE VALUES OF THE ERRORS."
440 PRINT: PRINT
450 PRINT" NUMBER OF OBSERVATIONS = ";ROWS
460 PRINT
470 PRINT"CORRELATION COEFFICIENT FOR THE RAW ERRORS = ";DARHO
480 PRINT
490 PRINT"CORRELATION COEFFICIENT FOR THE PERCENTAGE ERRORS = ";DRRHO
500 PRINT: PRINT
505 PRINT"BASED ON THE CRITICAL LEVELS IN APPENDIX B (FILLIBEN 1975) "
510 PRINT"IS THERE EVIDENCE TO CONTRADICT THE NORMALITY ASSUMPTION :
520 PRINT"          FOR THE RAW      ERRORS [Y/N]? --> ";: INPUT ANS1$
530 PRINT"        FOR THE PERCENTAGE ERRORS [Y/N]? --> ";: INPUT ANS2$
540 REM  BASED ON USER INPUT SELECT SEPARATE PATHS TO CALCULATE BIAS AND
550 REM  PRECISION OF ERRORS
552 DF=ROWS-1: REM SET DEGREES OF FREEDOM FOR T-TEST AS N-1
554 P=.025
556 PRINT:PRINT
558 PRINT"ENTER THE TWO-SIDED PROBABILITY LEVEL (DEFAULT=.05) --> ";: INPUT ANS$
560 IF VAL(ANS$)>0 THEN P=VAL(ANS$)/2
570 REM  COMPUTE RESULTS FOR THE ABSOLUTE ERRORS
580 FOR I=1 TO ROWS
590 TMP(I)=DA(I)
590 NEXT I
```

```
595 PRINT:PRINT"COMPUTE RESULTS FOR THE ABSOLUTE ERRORS": PRINT
600 IF ANS1$="Y" OR ANS1$="y" THEN GOSUB 13000 ELSE IF ANS1$="N" OR ANS1$="n" THEN
610 XBAR1=XBAR: CI1=CI: S1=S: PI1=PI
620 REM COMPUTE RESULTS FOR THE RELATIVE ERRORS
630 FOR I=1 TO ROWS
640 TMP(I)=DR(I)
650 NEXT I
655 PRINT:PRINT"COMPUTE RESULTS FOR THE RELATIVE ERRORS": PRINT
660 IF ANS2$="Y" OR ANS2$="y" THEN GOSUB 13000 ELSE IF ANS2$="N" OR ANS2$="n" THEN
670 XBAR2=XBAR: CI2=CI: S2=S: PI2=PI
680 REM DISPLAY THE RESULTS OF THE ANALYSIS
682 CLS
685 PRINT"THE NUMBER OF OBSERVATIONS [N] = ";ROWS: PRINT
684 PRINT"PLEASE ENTER THE VALUE FOR K FROM APPENDIX C (EISENHART, HASTAY"
686 PRINT",AND WALLIS 1947) SO THAT THE PROBABILITY IS GAMMA THAT AT LEAST"
688 PRINT"A PROPORTION P OF THE DISTRIBUTION OF FUTURE VALUES WILL BE"
689 PRINT"INCLUDED IN THE CALCULATED TOLERANCE INTERVALE --> ";: INPUT K
690 CLS
692 PRINT"RESULTS FOR ERRORS IN:";TAB(30) UNITS$; TAB(50) "PERCENT"
693 PRINT
694 PRINT"TWO SIDED PROB. LEVEL:";TAB(30) P*2; TAB(50) P*2
696 PRINT" BIAS ";TAB(30) XBAR1;TAB(50) XBAR2
698 PRINT"CONFIDENCE INTERVAL [+/-] :";TAB(30) CI1; TAB(50) CI2
700 PRINT"PREDICTION INTERVAL [+/-] :";TAB(30) PI1; TAB(50) PI2
705 PRINT"TOLERANCE  INTERVAL [+/-] :";TAB(30) S1*K;TAB(50) S2*K
710 PRINT"STANDARD DEVIATION :";TAB(30) S1;TAB(50) S2
715 PRINT"NUMBER OF OBSERVATIONS = ";ROWS
790 PRINT:PRINT:PRINT
800 IF DF> 5 THEN GOTO 820
810 PRINT"WARNING!!  THE PROCEDURE TO CALCULATE THE T-TABLE VALUE LOOSES"
812 PRINT"           ACCURACY WHEN THE DEGREES OF FREEDOM FALL BELOW 6."
820 PRINT:PRINT
830 PRINT"WHEN READY TO CONTINUE PRESS [RETURN] --> ";: INPUT ANS$
840 CLS
850 PRINT"ANOTHER SET OF DATA TO ANALYZE [Y/N]? --> ";: INPUT ANS$
860 IF ANS$="Y" OR ANS$="y" THEN GOTO 140
870 END
10000 REM  ************************************************************
10010 REM  **  SHELL-METZNER INPLACE, IN RAM SORT
10020 REM  **  INPUT:   ROWS= NUMBER OF PLACES IN ARRAY
10030 REM  **           ITAG$ CONTAINS ARRAY POINTER DA OR DR
10040 REM  ************************************************************
10050 M=ROWS: C1=0: S1=0
10060 M=INT(M/2)
10070 IF M=0 THEN GOTO 10230
10080 J=1: K=ROWS-M
10090 I=J
10100 L=I+M
10110 C1=C1+1
10120 IF ITAG$="DR" THEN GOTO 10150
10130 IF DA(I)<DA(L) THEN GOTO 10200
10140 T=DA(I): DA(I)=DA(L): DA(L)=T
10150 IF DR(I)<DR(L) THEN GOTO 10200
10160 T=DR(I): DR(I)=DR(L): DR(L)=T
10170 S1=S1+1: I=I-M
10180 IF I<1 THEN GOTO 10200
10190 GOTO 10100
10200 J=J+1
10210 IF J>K THEN GOTO 10060
10220 GOTO 10090
```

```
10230 RETURN
11000 REM  ************************************************************
11010 REM  **  TEST FOR HYPOTHESIS OF NORMALITY
11020 REM  **       LOCATION AND SCALE UNSPECIFIED
11030 REM  **  REFERENCE:  FILLIBEN,J.J. 1975. THE PROBABILITY PLOT
11040 REM  **              CORRELATION COEFFICIENT TEST FOR NORMALITY.
11050 REM  **              TECHNOMETRICS  17: 111-117
11060 REM  **  VERSION:  1/10/84
11070 REM  **  WRITTEN BY:  H.M. RAUSCHER, NCFES, GRAND RAPIDS, MN
11080 REM  ************************************************************
11090 REM  THE ORDERED ARRAY, SMALLEST TO LARGEST, MUST BE IN TMP(ROWS)
11100 REM  THE WORKING ARRAY MI(ROWS) MUST HAVE BEEN DIMENSIONED ALREADY
11102 REM  INITIALIZATION
11105 C0=2.515517: C1=.802853: C2=.010328
11106 D1=1.432788: D2=.189269: D3=.001308
11110 REM
11120 REM  FILL IN THE MI(.) ARRAY
11130 MI(ROWS)=.5^(1/ROWS)
11140 MI(1)=1-MI(ROWS)
11150 FOR I=2 TO ROWS-1
11160 MI(I)=(I-.3175)/(ROWS+.365)
11170 NEXT I
11175 J=0
11180 FOR I= 1 TO ROWS
11184 IF MI(I)<=.5 THEN J=J+1
11185 IF MI(I)>.5 THEN MI(I)=1!-MI(I)
11190 TN=SQR(LOG(1/(MI(I)*MI(I))))
11200 MI(I)=TN-(C0+C1*TN+C2*TN*TN)/(1+D1*TN+D2*TN*TN+D3*TN*TN*TN)
11207 IF ABS(MI(I))<.00001 THEN MI(I)=0
11210 NEXT I
11212 FOR I=1 TO J
11214 MI(I)=-MI(I)
11216 NEXT I
11220 REM  COMPUTE THE AVERAGE VALUE FOR TMP(.)
11230 XBAR=0:SUM1=0
11240 FOR I= 1 TO ROWS
11250 SUM1=SUM1+TMP(I)
11260 NEXT I
11262 XBAR=SUM1/ROWS
11270 REM COMPUTE THE CORRELATION COEFFICIENT
11280 SUM1=0: SUM2=0: SUM3=0
11290 FOR I=1 TO ROWS
11300 SUM1=SUM1+TMP(I)*MI(I)
11310 SUM2=SUM2+MI(I)*MI(I)
11320 SUM3=SUM3+(TMP(I)-XBAR)^2
11330 NEXT I
11340 RHO=SUM1/SQR(SUM2*SUM3)
11350 REM  RETURN THE VALUE OF RHO AND ROWS TO CALLING PROGRAM
11360 RETURN
12000 REM  ************************************************
12010 REM  **  ROUTINE TO COMPUTE BIAS AND PRECISION WHEN NORMALITY ASSUMED
12020 REM  ************************************************
12030 SUM1=0: SUM2=0
12040 FOR I=1 TO ROWS
12050 SUM1=SUM1+TMP(I)
12060 SUM2=SUM2+TMP(I)*TMP(I)
12070 NEXT I
12080 XBAR=SUM1/ROWS
12090 S=SUM2-(SUM1*SUM1)/ROWS:S=SQR(S/(ROWS-1))
12100 REM  COMPUTE THE T-TABLE VALUE , TT
```

```
12110 GOSUB 15000
12120 REM  COMPUTE CONFIDENCE INTERVAL
12130 CI=S*TT/SQR(ROWS)
12140 REM COMPUTE THE PREDICTION INTERVAL
12150 PI=S*TT*SQR(1+1/ROWS)
12160 RETURN
13000 REM  ******************************************************
13010 REM  ** ROUTINE TO COMPUTE ACCURACY WHEN ERROR NOT NORMAL
13020 REM  ******************************************************
13030 REM COMPUTE THE 10% TRIMMED MEAN
13040 J=INT(ROWS*.1+.5)
13050 IF J=0 THEN J=1: REM AT LEAST TRIM THE EXTREMES
13060 SUM1=0:N=0
13070 FOR I=J+1 TO ROWS-J
13080 SUM1=SUM1+TMP(I): N=N+1
13090 NEXT I
13100 XBAR=SUM1/N
13102 REM COMPUTE THE FULL SAMPLE S, FSS
13104 SUM1=0:SUM2=0
13106 FOR I=1 TO ROWS: SUM1=SUM1+TMP(I):SUM2=SUM2+TMP(I)*TMP(I): NEXT I
13108 FSS=SUM2-(SUM1*SUM1)/ROWS: FSS=SQR(FSS/(ROWS-1))
13110 REM COMPUTE THE JACKKNIFE STANDARD DEVIATION
13120 SUM3=0
13130 FOR J=1 TO ROWS
13140 SUM1=0:SUM2=0
13150 FOR I=1 TO ROWS
13160 IF I=J THEN GOTO 13190
13170 SUM1=SUM1+TMP(I)
13180 SUM2=SUM2+TMP(I)*TMP(I)
13190 NEXT I
13200 S=SUM2-(SUM1*SUM1)/(ROWS-1): S=SQR(S/(ROWS-2))
13210 SUM3=SUM3+(ROWS*FSS-(ROWS-1)*S)
13220 NEXT J
13230 S=SUM3/ROWS
13240 REM COMPUTE THE T-TABLE VALUE, TT
13250 GOSUB 15000
13260 REM COMPUTE CONFIDENCE INTERVAL
13270 CI=S*TT/SQR(ROWS)
13280 REM COMPUTE PREDICTION INTERVAL
13290 PI=S*TT*SQR(1+1/ROWS)
13300 RETURN
14000 REM  ******************************************************
14010 PRINT:PRINT
14020 PRINT"AN INPUT ERROR HAS BEEN DETECTED.  PLEASE ENTER ONLY [Y],[y],[N],"
14030 PRINT"OR [n] WHEN ASKED TO ENTER [Y/N] ! "
14040 PRINT"PLEASE PRESS [RETURN] TO TRY AGAIN";: INPUT ANS1$
14050 GOTO 410
15000 REM  ******************************************************
15010 REM  ** ROUTINE TO COMPUTE THE T-TABLE VALUE GIVEN DEGREES OF
15020 REM  **    FREEDOM (DF) AND THE TWO SIDED ALPHA LEVEL
15030 REM  **REFERENCE:  SHAMMAS,NAMIR C. 1984. STATISTICAL TABLE
15040 REM  **             SUBROUTINES.  ACCESS 3:19-22
15050 REM  ** VERSION:  1/10/85
15060 REM  ******************************************************
15070 REM  WARNING:  ROUTINE ACCURATE TO 3 DIGITS, LOOSING ACCURACY AT
15080 REM            LOW VALUES OF THE DEGREES OF FREEDOM
15130 IF P>.5 THEN U0=SQR(LOG(1/(1-P)^2)) ELSE U0=SQR(LOG(1/P/P))
15140 U1=((.010328*U0)+.802853)*U0+2.515517
15150 U2=(((.001308*U0)+.189269)*U0+1.432788)*U0+1
15160 XP=U0-U1/U2
```

```
15170 IF P > .5 THEN XP=-XP
15180 U0=XP^2
15190 U1=XP/4*(U0+1)
15200 U2=(5*U0^2+76*U0+5)*XP/96
15210 U3=(3*U0^3+19*U0^2+17*U0-15)*XP/384
15220 U4=(179*U0^4+1376*U0^3+1482*U0^2-1920*U0-945)*XP/921601
15230 TT=XP+U1/DF+U2/DF^2+U3/DF^3+U4/DF^4
15240 RETURN
20000 '*************************************************************************
20010 '*   ROUTINE TO CHECK AND EDIT DATA IN CASE OF ENTRY ERROR
20020 '*************************************************************************
20030 CLS:INPUT"DO YOU WANT TO REVIEW YOUR DATA (Y/N)  --> ";ANS$
20040 IF ANS$="N" OR ANS$="n" THEN GOTO 20210
20050 PRINT:PRINT
20060 I=0
20070 FOR J=1 TO 10
20075 I=I+1: IF I>ROWS THEN GOTO 20100
20080 PRINT"PAIR NO.:  ";I;" STANDARD (Y):  ";Y(I);"    COMPETITOR (X):  ";X(I)
20090 NEXT J
20100 PRINT:PRINT
20110 INPUT "CORRECT (Y/N) --> ";ANS$
20120 IF ANS$="Y" OR ANS$="y" THEN GOTO 20180
20130 ' ALLOW EDITING OF DATA
20140 PRINT"ENTER A TRIPLET: [PAIR NO., STANDARD(Y), COMPETITOR(X)]"
20150 PRINT"          TO FINISH:  ENTER [0,0,0]"
20160 PRINT: INPUT II,Y(II),X(II)
20162 IF II<=0 THEN GOTO 20175
20165 DA(II)=Y(II)-X(II):DR(II)=100*(DA(II)/Y(II))
20170 IF II>0 THEN GOTO 20160
20175 I=INT((I-1)/10)*10:' DISPLAY AGAIN THE LAST PAGE
20178 GOTO 20070
20180 IF I>ROWS THEN GOTO 20210
20185 PRINT:INPUT"REVIEW THE NEXT 10 PAIRS (Y/N) --> ";ANS$
20186 PRINT:PRINT
20190 IF ANS$="N" OR ANS$="n" THEN GOTO 20210
20200 GOTO 20070
20210 RETURN
20220 END
```

APPENDIX B. PERCENT POINTS OF THE NORMAL PROBABILITY CORRELATION COEFFICIENT (Filliben 1975, Table 1)

n	Probability Level													
	.000	.005	.01	.025	.05	.10	.25	.50	.75	.90	.95	.975	.99	.995
3	.866	.867	.869	.872	.879	.891	.924	.966	.991	.999	1.000	1.000	1.000	1.000
4	.784	.813	.822	.845	.868	.894	.931	.958	.979	.992	.996	.998	.999	1.000
5	.726	.803	.822	.855	.879	.902	.935	.960	.977	.988	.992	.995	.997	.998
6	.683	.818	.835	.868	.890	.911	.940	.962	.977	.986	.990	.993	.996	.997
7	.648	.828	.847	.876	.899	.916	.944	.965	.978	.986	.990	.992	.995	.996
8	.619	.841	.859	.886	.905	.924	.948	.967	.979	.986	.990	.992	.995	.996
9	.595	.851	.868	.893	.912	.929	.951	.968	.980	.987	.990	.992	.994	.995
10	.574	.860	.876	.900	.917	.934	.954	.970	.981	.987	.990	.992	.994	.995
11	.556	.868	.883	.906	.922	.938	.957	.972	.982	.988	.990	.992	.994	.995
12	.539	.875	.889	.912	.926	.941	.959	.973	.982	.988	.990	.992	.994	.995
13	.525	.882	.895	.917	.931	.944	.962	.975	.983	.988	.991	.993	.994	.995
14	.512	.888	.901	.921	.934	.947	.964	.976	.984	.989	.991	.993	.994	.995
15	.500	.894	.907	.925	.937	.950	.965	.977	.984	.989	.991	.993	.994	.995
16	.489	.899	.912	.928	.940	.952	.967	.978	.985	.989	.991	.993	.994	.995
17	.478	.903	.916	.931	.942	.954	.968	.979	.986	.990	.992	.993	.994	.995
18	.469	.907	.919	.934	.945	.956	.969	.979	.986	.990	.992	.993	.995	.995
19	.460	.909	.923	.937	.947	.958	.971	.980	.987	.990	.992	.993	.995	.995
20	.452	.912	.925	.939	.950	.960	.972	.981	.987	.991	.992	.994	.995	.995
21	.445	.914	.928	.942	.952	.961	.973	.981	.987	.991	.993	.994	.995	.996
22	.437	.918	.930	.944	.954	.962	.974	.982	.988	.991	.993	.994	.995	.996
23	.431	.922	.933	.947	.955	.964	.975	.983	.988	.991	.993	.994	.995	.996
24	.424	.926	.936	.949	.957	.965	.975	.983	.988	.992	.993	.994	.995	.996
25	.418	.928	.937	.950	.958	.966	.976	.984	.989	.992	.993	.994	.995	.996
26	.412	.930	.939	.952	.959	.967	.977	.984	.989	.992	.993	.994	.995	.996
27	.407	.932	.941	.953	.960	.968	.977	.984	.989	.992	.994	.995	.995	.996
28	.402	.934	.943	.955	.962	.969	.978	.985	.990	.992	.994	.995	.995	.996
29	.397	.937	.945	.956	.962	.969	.979	.985	.990	.992	.994	.995	.995	.996
30	.392	.938	.947	.957	.964	.970	.979	.986	.990	.993	.994	.995	.996	.996
31	.388	.939	.948	.958	.965	.971	.980	.986	.990	.993	.994	.995	.996	.996
32	.383	.939	.949	.959	.966	.972	.980	.986	.990	.993	.994	.995	.996	.996
33	.379	.940	.950	.960	.967	.973	.981	.987	.991	.993	.994	.995	.996	.996
34	.375	.941	.951	.960	.967	.973	.981	.987	.991	.993	.994	.995	.996	.996
35	.371	.943	.952	.961	.968	.974	.982	.987	.991	.993	.995	.995	.996	.997
36	.367	.945	.953	.962	.968	.974	.982	.987	.991	.994	.995	.996	.996	.997
37	.364	.947	.955	.962	.969	.975	.982	.988	.991	.994	.995	.996	.996	.997
38	.360	.948	.956	.964	.970	.975	.983	.988	.992	.994	.995	.996	.996	.997
39	.357	.949	.957	.965	.971	.976	.983	.988	.992	.994	.995	.996	.996	.997
40	.354	.949	.958	.966	.972	.977	.983	.988	.992	.994	.995	.996	.996	.997
41	.351	.950	.958	.967	.972	.977	.984	.989	.992	.994	.995	.996	.996	.997
42	.348	.951	.959	.967	.973	.978	.984	.989	.992	.994	.995	.996	.997	.997
43	.345	.953	.959	.967	.973	.978	.984	.989	.992	.994	.995	.996	.997	.997
44	.342	.954	.960	.968	.973	.978	.984	.989	.992	.994	.995	.996	.997	.997
45	.339	.955	.961	.969	.974	.978	.985	.989	.993	.994	.995	.996	.997	.997
46	.336	.956	.962	.969	.974	.979	.985	.990	.993	.995	.995	.996	.997	.997
47	.334	.956	.963	.970	.974	.979	.985	.990	.993	.995	.995	.996	.997	.997
48	.331	.957	.963	.970	.975	.980	.985	.990	.993	.995	.996	.996	.997	.997
49	.329	.957	.964	.971	.975	.980	.986	.990	.993	.995	.996	.996	.997	.997
50	.326	.959	.965	.972	.977	.981	.986	.990	.993	.995	.996	.996	.997	.997
55	.315	.962	.967	.974	.978	.982	.987	.991	.994	.995	.996	.997	.997	.997
60	.305	.965	.970	.976	.980	.983	.988	.991	.994	.995	.996	.997	.997	.998
65	.296	.967	.972	.977	.981	.984	.989	.992	.994	.996	.996	.997	.997	.998
70	.288	.969	.974	.978	.982	.985	.989	.993	.995	.996	.997	.997	.998	.998
75	.281	.971	.975	.979	.983	.986	.990	.993	.995	.996	.997	.997	.998	.998
80	.274	.973	.976	.980	.984	.987	.991	.993	.995	.996	.997	.997	.998	.998
85	.268	.974	.977	.981	.985	.987	.991	.994	.995	.997	.997	.997	.998	.998
90	.263	.976	.978	.982	.985	.988	.991	.994	.996	.997	.997	.998	.998	.998
95	.257	.977	.979	.983	.986	.989	.992	.994	.996	.997	.997	.998	.998	.998
100	.252	.979	.981	.984	.987	.989	.992	.994	.996	.997	.998	.998	.998	.998

APPENDIX C. TABULATION OF TOLLERANCE FACTORS FOR THE NORMAL DISTRIBUTION (Eisenhart *et al*. 1947, Table 2.1)

TOLERANCE FACTORS FOR NORMAL DISTRIBUTIONS

Factors K such that the probability is γ that at least a proportion P of the distribution will be included between $\bar{X} \pm Ks$, where $\bar{X}$ and s are estimates of the mean and the standard deviation computed from a sample of N (Eisenhart *et al.* 1947).

	γ = 0.75					γ = 0.90					γ = 0.95					γ = 0.99				
N/P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
2	4.498	6.301	7.414	9.531	11.920	11.407	15.978	18.800	24.167	30.227	22.858	32.019	37.674	48.430	60.573	114.363	160.193	188.491	242.300	303.054
3	2.501	3.538	4.187	5.431	6.844	4.132	5.847	6.919	8.974	11.309	5.922	8.380	9.916	12.861	16.208	13.378	18.930	22.401	29.055	36.616
4	2.035	2.892	3.431	4.471	5.657	2.932	4.166	4.943	6.440	8.149	3.779	5.369	6.370	8.299	10.502	6.614	9.398	11.150	14.527	18.383
5	1.825	2.599	3.088	4.033	5.117	2.454	3.494	4.152	5.423	6.879	3.002	4.275	5.079	6.634	8.415	4.643	6.612	7.855	10.260	13.015
6	1.704	2.429	2.889	3.779	4.802	2.196	3.131	3.723	4.870	6.188	2.604	3.712	4.414	5.775	7.337	3.743	5.337	6.345	8.301	10.548
7	1.624	2.318	2.757	3.611	4.593	2.034	2.902	3.452	4.521	5.750	2.361	3.369	4.007	5.248	6.676	3.283	4.613	5.488	7.187	9.142
8	1.568	2.238	2.663	3.491	4.444	1.921	2.743	3.264	4.278	5.446	2.197	3.136	3.732	4.891	6.226	2.905	4.147	4.936	6.468	8.234
9	1.525	2.178	2.593	3.400	4.330	1.839	2.626	3.125	4.098	5.220	2.078	2.967	3.532	4.631	5.899	2.677	3.822	4.550	5.966	7.600
10	1.492	2.131	2.537	3.328	4.241	1.775	2.535	3.018	3.959	5.046	1.987	2.839	3.379	4.433	5.649	2.508	3.582	4.265	5.594	7.129
11	1.465	2.093	2.493	3.271	4.169	1.724	2.463	2.933	3.849	4.906	1.916	2.737	3.259	4.277	5.452	2.378	3.397	4.045	5.308	6.766
12	1.443	2.062	2.456	3.223	4.110	1.683	2.404	2.863	3.758	4.792	1.858	2.655	3.162	4.150	5.291	2.274	3.250	3.870	5.079	6.477
13	1.425	2.036	2.424	3.183	4.059	1.648	2.355	2.805	3.682	4.697	1.810	2.587	3.081	4.044	5.158	2.190	3.130	3.727	4.893	6.240
14	1.409	2.013	2.398	3.148	4.016	1.619	2.314	2.756	3.618	4.615	1.770	2.529	3.012	3.955	5.045	2.120	3.029	3.608	4.737	6.043
15	1.395	1.994	2.375	3.118	3.979	1.594	2.278	2.713	3.562	4.545	1.735	2.480	2.954	3.878	4.949	2.060	2.945	3.507	4.605	5.876
16	1.383	1.977	2.355	3.092	3.946	1.572	2.246	2.676	3.514	4.484	1.705	2.437	2.903	3.812	4.865	2.009	2.872	3.421	4.492	5.732
17	1.372	1.962	2.337	3.069	3.917	1.552	2.219	2.643	3.471	4.430	1.679	2.400	2.858	3.754	4.791	1.965	2.808	3.345	4.393	5.607
18	1.363	1.948	2.321	3.048	3.891	1.535	2.194	2.614	3.433	4.382	1.655	2.366	2.819	3.702	4.725	1.926	2.753	3.279	4.307	5.497
19	1.355	1.936	2.307	3.030	3.867	1.520	2.172	2.588	3.399	4.339	1.635	2.337	2.784	3.656	4.667	1.891	2.703	3.221	4.230	5.399
20	1.347	1.925	2.294	3.013	3.846	1.506	2.152	2.564	3.368	4.300	1.616	2.310	2.752	3.615	4.614	1.860	2.659	3.168	4.161	5.312
21	1.340	1.915	2.282	2.998	3.827	1.493	2.135	2.543	3.340	4.264	1.599	2.286	2.723	3.577	4.567	1.833	2.620	3.121	4.100	5.234
22	1.334	1.906	2.271	2.984	3.809	1.482	2.118	2.524	3.315	4.232	1.584	2.264	2.697	3.543	4.523	1.808	2.584	3.078	4.044	5.163
23	1.328	1.898	2.261	2.971	3.793	1.471	2.103	2.506	3.292	4.203	1.570	2.244	2.673	3.512	4.484	1.785	2.551	3.040	3.993	5.098
24	1.322	1.891	2.252	2.959	3.778	1.462	2.089	2.489	3.270	4.176	1.557	2.225	2.651	3.483	4.447	1.764	2.522	3.004	3.947	5.039
25	1.317	1.883	2.244	2.948	3.764	1.453	2.077	2.474	3.251	4.151	1.545	2.208	2.631	3.457	4.413	1.745	2.494	2.972	3.904	4.985
26	1.313	1.877	2.236	2.938	3.751	1.444	2.065	2.460	3.232	4.127	1.534	2.193	2.612	3.432	4.382	1.727	2.469	2.941	3.865	4.935
27	1.309	1.871	2.229	2.929	3.740	1.437	2.054	2.447	3.215	4.106	1.523	2.178	2.595	3.409	4.353	1.711	2.446	2.914	3.828	4.888
28	1.305	1.865	2.222	2.920	3.728	1.430	2.044	2.435	3.199	4.085	1.514	2.164	2.579	3.388	4.326	1.695	2.424	2.888	3.794	4.845
29	1.301	1.860	2.216	2.911	3.718	1.423	2.034	2.424	3.184	4.066	1.505	2.152	2.564	3.368	4.301	1.681	2.404	2.864	3.763	4.805
30	1.297	1.855	2.210	2.904	3.708	1.417	2.025	2.413	3.170	4.049	1.497	2.140	2.549	3.350	4.278	1.668	2.385	2.841	3.733	4.768
31	1.294	1.850	2.204	2.896	3.699	1.411	2.017	2.403	3.157	4.032	1.489	2.129	2.536	3.332	4.256	1.656	2.367	2.820	3.706	4.732

	γ = 0.75					γ = 0.90					γ = 0.95					γ = 0.99				
N/P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
32	1.291	1.846	2.199	2.890	3.690	1.405	2.009	2.393	3.145	4.016	1.481	2.118	2.524	3.316	4.235	1.644	2.351	2.801	3.680	4.699
33	1.288	1.842	2.194	2.883	3.682	1.400	2.001	2.385	3.133	4.001	1.475	2.108	2.512	3.300	4.215	1.633	2.335	2.782	3.655	4.668
34	1.285	1.838	2.189	2.877	3.674	1.395	1.994	2.376	3.122	3.987	1.468	2.099	2.501	3.286	4.197	1.623	2.320	2.764	3.632	4.639
35	1.283	1.834	2.185	2.871	3.667	1.390	1.988	2.368	3.112	3.974	1.462	2.090	2.490	3.272	4.179	1.613	2.306	2.748	3.611	4.611
36	1.280	1.830	2.181	2.866	3.660	1.386	1.981	2.361	3.102	3.961	1.455	2.081	2.479	3.258	4.161	1.604	2.293	2.732	3.590	4.585
37	1.278	1.827	2.177	2.860	3.653	1.381	1.975	2.353	3.092	3.949	1.450	2.073	2.470	3.246	4.146	1.595	2.281	2.717	3.571	4.560
38	1.275	1.824	2.173	2.855	3.647	1.377	1.969	2.346	3.083	3.938	1.446	2.068	2.464	3.237	4.134	1.587	2.269	2.703	3.552	4.537
39	1.273	1.821	2.169	2.850	3.641	1.374	1.964	2.340	3.075	3.927	1.441	2.060	2.455	3.226	4.120	1.579	2.257	2.690	3.534	4.514
40	1.271	1.818	2.166	2.846	3.635	1.370	1.959	2.334	3.066	3.917	1.435	2.052	2.445	3.213	4.104	1.571	2.247	2.677	3.518	4.493
41	1.269	1.815	2.162	2.841	3.629	1.366	1.954	2.328	3.059	3.907	1.430	2.045	2.437	3.202	4.090	1.564	2.236	2.665	3.502	4.472
42	1.267	1.812	2.159	2.837	3.624	1.363	1.949	2.322	3.051	3.897	1.426	2.039	2.429	3.192	4.077	1.557	2.227	2.653	3.486	4.453
43	1.266	1.810	2.156	2.833	3.619	1.360	1.944	2.316	3.044	3.888	1.422	2.033	2.422	3.183	4.065	1.551	2.217	2.642	3.472	4.434
44	1.264	1.807	2.153	2.829	3.614	1.357	1.940	2.311	3.037	3.879	1.418	2.027	2.415	3.173	4.053	1.545	2.208	2.631	3.458	4.416
45	1.262	1.805	2.150	2.826	3.609	1.354	1.935	2.306	3.030	3.871	1.414	2.021	2.408	3.165	4.042	1.539	2.200	2.621	3.444	4.399
46	1.261	1.802	2.148	2.822	3.605	1.351	1.931	2.301	3.024	3.863	1.410	2.016	2.402	3.156	4.031	1.533	2.192	2.611	3.431	4.383
47	1.259	1.800	2.145	2.819	3.600	1.348	1.927	2.297	3.018	3.855	1.406	2.011	2.396	3.148	4.021	1.527	2.184	2.602	3.419	4.367
48	1.258	1.798	2.143	2.815	3.596	1.345	1.924	2.292	3.012	3.847	1.403	2.006	2.390	3.140	4.011	1.522	2.176	2.593	3.407	4.352
49	1.256	1.796	2.140	2.812	3.592	1.343	1.920	2.288	3.006	3.840	1.399	2.001	2.384	3.133	4.002	1.517	2.169	2.584	3.396	4.337
50	1.255	1.794	2.138	2.809	3.588	1.340	1.916	2.284	3.001	3.833	1.396	1.996	2.379	3.126	3.993	1.512	2.162	2.576	3.385	4.323
51	1.253	1.792	2.135	2.806	3.584	1.338	1.913	2.279	2.995	3.826	1.393	1.992	2.373	3.119	3.984	1.507	2.155	2.568	3.374	4.310
52	1.252	1.790	2.133	2.803	3.581	1.336	1.910	2.276	2.990	3.820	1.390	1.988	2.368	3.112	3.975	1.503	2.148	2.560	3.364	4.297
53	1.251	1.789	2.131	2.801	3.577	1.334	1.907	2.272	2.985	3.813	1.387	1.984	2.363	3.106	3.967	1.498	2.142	2.552	3.354	4.284
54	1.250	1.787	2.129	2.798	3.574	1.331	1.904	2.268	2.981	3.807	1.384	1.980	2.359	3.100	3.959	1.494	2.136	2.545	3.344	4.272
55	1.249	1.785	2.127	2.795	3.571	1.329	1.901	2.265	2.976	3.801	1.382	1.976	2.354	3.094	3.951	1.490	2.130	2.538	3.335	4.260
56	1.247	1.784	2.125	2.793	3.567	1.327	1.898	2.261	2.972	3.796	1.379	1.972	2.350	3.088	3.944	1.486	2.124	2.531	3.326	4.249
57	1.246	1.782	2.123	2.790	3.564	1.325	1.895	2.258	2.967	3.790	1.377	1.968	2.345	3.082	3.937	1.482	2.119	2.524	3.318	4.238
58	1.245	1.781	2.122	2.788	3.561	1.323	1.892	2.255	2.963	3.785	1.374	1.965	2.341	3.076	3.930	1.478	2.113	2.518	3.309	4.227
59	1.244	1.779	2.120	2.786	3.558	1.322	1.890	2.252	2.959	3.779	1.372	1.961	2.337	3.071	3.923	1.474	2.108	2.512	3.301	4.216
60	1.243	1.778	2.118	2.784	3.556	1.320	1.887	2.248	2.955	3.774	1.369	1.958	2.333	3.066	3.916	1.471	2.103	2.506	3.293	4.206
61	1.242	1.776	2.117	2.781	3.553	1.318	1.885	2.245	2.951	3.769	1.367	1.955	2.329	3.061	3.909	1.467	2.098	2.500	3.285	4.196
62	1.241	1.775	2.115	2.779	3.550	1.316	1.882	2.243	2.947	3.765	1.365	1.951	2.325	3.056	3.903	1.464	2.093	2.494	3.278	4.187
63	1.240	1.774	2.113	2.777	3.548	1.315	1.880	2.240	2.944	3.760	1.363	1.948	2.322	3.051	3.897	1.461	2.089	2.489	3.271	4.178
64	1.240	1.772	2.112	2.775	3.545	1.313	1.878	2.237	2.940	3.755	1.361	1.945	2.318	3.046	3.891	1.458	2.084	2.483	3.264	4.169
65	1.239	1.771	2.110	2.773	3.543	1.312	1.875	2.235	2.937	3.751	1.359	1.943	2.315	3.042	3.886	1.455	2.080	2.478	3.257	4.160
66	1.238	1.770	2.109	2.771	3.540	1.310	1.873	2.232	2.933	3.747	1.357	1.940	2.311	3.037	3.880	1.452	2.076	2.473	3.250	4.152

	γ = 0.75					γ = 0.90					γ = 0.95					γ = 0.99				
N/P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
67	1.237	1.769	2.108	2.770	3.538	1.309	1.871	2.229	2.930	3.742	1.355	1.937	2.308	3.033	3.874	1.449	2.071	2.468	3.244	4.143
68	1.236	1.768	2.106	2.768	3.536	1.307	1.869	2.227	2.927	3.738	1.358	1.934	2.305	3.029	3.869	1.446	2.067	2.463	3.237	4.135
69	1.235	1.766	2.105	2.766	3.533	1.306	1.867	2.225	2.923	3.734	1.351	1.932	2.302	3.025	3.864	1.443	2.063	2.459	3.231	4.127
70	1.235	1.765	2.104	2.764	3.531	1.304	1.865	2.222	2.920	3.730	1.349	1.929	2.299	3.021	3.859	1.440	2.060	2.454	3.225	4.120
71	1.234	1.764	2.102	2.763	3.529	1.303	1.863	2.220	2.917	3.727	1.347	1.927	2.296	3.017	3.854	1.438	2.056	2.450	3.219	4.112
72	1.233	1.763	2.101	2.761	3.527	1.302	1.861	2.218	2.915	3.723	1.346	1.924	2.293	3.013	3.849	1.435	2.052	2.445	3.214	4.105
73	1.233	1.762	2.100	2.760	3.525	1.300	1.859	2.216	2.912	3.719	1.344	1.922	2.290	3.009	3.844	1.433	2.049	2.441	3.208	4.098
74	1.232	1.761	2.099	2.758	3.523	1.299	1.858	2.214	2.909	3.716	1.343	1.920	2.287	3.006	3.840	1.430	2.045	2.437	3.203	4.091
75	1.231	1.760	2.098	2.757	3.521	1.298	1.856	2.211	2.906	3.712	1.341	1.917	2.285	3.002	3.835	1.428	2.042	2.433	3.197	4.084
76	1.230	1.759	2.096	2.755	3.519	1.297	1.854	2.209	2.904	3.709	1.339	1.915	2.282	2.999	3.831	1.426	2.039	2.429	3.192	4.078
77	1.230	1.758	2.095	2.754	3.517	1.296	1.853	2.207	2.901	3.706	1.338	1.913	2.279	2.996	3.826	1.423	2.035	2.425	3.187	4.071
78	1.229	1.758	2.094	2.752	3.516	1.295	1.851	2.206	2.898	3.702	1.336	1.911	2.277	2.992	3.822	1.421	2.032	2.421	3.182	4.065
79	1.229	1.757	2.093	2.751	3.514	1.293	1.849	2.204	2.896	3.699	1.335	1.909	2.274	2.989	3.818	1.419	2.029	2.418	3.177	4.059
80	1.228	1.756	2.092	2.749	3.512	1.292	1.848	2.202	2.894	3.696	1.334	1.907	2.272	2.986	3.814	1.417	2.026	2.414	3.173	4.053
81	1.227	1.755	2.091	2.748	3.510	1.291	1.846	2.200	2.891	3.693	1.332	1.905	2.270	2.983	3.810	1.415	2.023	2.411	3.168	4.047
82	1.227	1.754	2.090	2.747	3.509	1.290	1.845	2.198	2.889	3.690	1.331	1.903	2.267	2.980	3.806	1.413	2.020	2.407	3.163	4.041
83	1.226	1.753	2.089	2.746	3.507	1.289	1.843	2.196	2.887	3.687	1.329	1.901	2.265	2.977	3.803	1.411	2.017	2.404	3.159	4.035
84	1.226	1.753	2.088	2.744	3.506	1.288	1.842	2.195	2.884	3.684	1.328	1.899	2.263	2.974	3.799	1.409	2.014	2.400	3.155	4.030
85	1.225	1.752	2.087	2.743	3.504	1.287	1.841	2.193	2.882	3.682	1.327	1.897	2.261	2.971	3.795	1.407	2.012	2.397	3.150	4.024
86	1.225	1.751	2.086	2.742	3.503	1.286	1.839	2.191	2.880	3.679	1.326	1.896	2.259	2.968	3.792	1.405	2.009	2.394	3.146	4.019
87	1.224	1.750	2.086	2.741	3.501	1.285	1.838	2.190	2.878	3.676	1.324	1.894	2.257	2.966	3.788	1.403	2.007	2.391	3.142	4.014
88	1.224	1.749	2.085	2.740	3.500	1.284	1.837	2.188	2.876	3.674	1.323	1.892	2.255	2.963	3.785	1.402	2.004	2.388	3.138	4.000
89	1.223	1.749	2.084	2.738	3.498	1.284	1.835	2.187	2.874	3.671	1.322	1.890	2.253	2.960	3.781	1.400	2.001	2.385	3.134	4.004
90	1.223	1.748	2.083	2.737	3.497	1.283	1.834	2.185	2.872	3.669	1.321	1.889	2.251	2.958	3.778	1.398	1.999	2.382	3.130	3.999
91	1.222	1.747	2.082	2.736	3.495	1.282	1.833	2.184	2.870	3.666	1.320	1.887	2.249	2.955	3.775	1.396	1.997	2.379	3.127	3.994
92	1.222	1.747	2.081	2.735	3.494	1.281	1.832	2.182	2.868	3.664	1.319	1.886	2.247	2.953	3.772	1.395	1.994	2.376	3.123	3.989
93	1.221	1.746	2.081	2.734	3.493	1.280	1.830	2.181	2.866	3.661	1.318	1.884	2.245	2.950	3.769	1.393	1.992	2.373	3.119	3.985
94	1.221	1.745	2.080	2.733	3.491	1.279	1.829	2.180	2.864	3.659	1.317	1.882	2.243	2.948	3.766	1.392	1.990	2.371	3.116	3.980
95	1.220	1.745	2.079	2.732	3.490	1.278	1.828	2.178	2.863	3.657	1.315	1.881	2.241	2.945	3.763	1.390	1.987	2.368	3.112	3.976
96	1.220	1.744	2.078	2.731	3.489	1.278	1.287	2.177	2.861	3.654	1.314	1.880	2.240	2.943	3.760	1.388	1.985	2.366	3.109	3.971
97	1.219	1.743	2.077	2.730	3.488	1.277	1.826	2.175	2.859	3.652	1.313	1.878	2.238	2.941	3.757	1.387	1.983	2.363	3.105	3.967
98	1.219	1.743	2.077	2.729	3.486	1.276	1.825	2.174	2.857	3.650	1.312	1.877	2.236	2.939	3.754	1.385	1.981	2.360	3.102	3.963
99	1.219	1.742	2.076	2.728	3.485	1.275	1.824	2.173	2.856	3.648	1.311	1.875	2.234	2.936	3.751	1.384	1.979	2.358	3.099	3.958
100	1.218	1.742	2.075	2.727	3.484	1.275	1.822	2.172	2.854	3.646	1.311	1.874	2.233	2.934	3.748	1.383	1.977	2.355	3.096	3.954
101	1.218	1.741	2.075	2.726	3.483	1.274	1.821	2.170	2.852	3.644	1.310	1.872	2.231	2.932	3.746	1.381	1.975	2.353	3.092	3.950

	γ = 0.75					γ = 0.90					γ = 0.95					γ = 0.99				
N/P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
102	1.217	1.741	2.074	2.726	3.482	1.273	1.820	2.169	2.851	3.642	1.309	1.871	2.230	2.930	3.743	1.380	1.973	2.351	3.089	3.946
104	1.217	1.739	2.073	2.724	3.480	1.272	1.818	2.167	2.848	3.638	1.307	1.869	2.227	2.926	3.738	1.377	1.969	2.346	3.083	3.939
106	1.216	1.738	2.071	2.722	3.477	1.270	1.816	2.164	2.845	3.634	1.305	1.866	2.224	2.922	3.733	1.374	1.965	2.342	3.077	3.931
108	1.215	1.737	2.070	2.721	3.475	1.269	1.815	2.162	2.842	3.630	1.303	1.864	2.221	2.918	3.728	1.372	1.962	2.337	3.072	3.924
110	1.214	1.736	2.069	2.719	3.473	1.268	1.813	2.160	2.839	3.626	1.302	1.861	2.218	2.915	3.723	1.369	1.958	2.333	3.066	3.917
112	1.214	1.735	2.068	2.717	3.471	1.267	1.811	2.158	2.836	3.623	1.300	1.859	2.215	2.911	3.719	1.367	1.955	2.329	3.061	3.910
114	1.213	1.734	2.067	2.716	3.469	1.265	1.809	2.156	2.833	3.619	1.299	1.857	2.212	2.908	3.714	1.365	1.951	2.325	3.056	3.904
116	1.212	1.733	2.065	2.714	3.468	1.264	1.808	2.154	2.831	3.616	1.297	1.855	2.210	2.904	3.710	1.363	1.948	2.321	3.051	3.897
118	1.212	1.733	2.064	2.713	3.466	1.263	1.806	2.152	2.828	3.613	1.296	1.852	2.207	2.901	3.706	1.360	1.945	2.318	3.046	3.891
120	1.211	1.732	2.063	2.712	3.464	1.262	1.804	2.150	2.826	3.610	1.294	1.850	2.205	2.898	3.702	1.358	1.942	2.314	3.041	3.885
122	1.210	1.731	2.062	2.710	3.462	1.261	1.803	2.148	2.823	3.607	1.293	1.848	2.203	2.895	3.698	1.356	1.939	2.311	3.037	3.879
124	1.210	1.730	2.061	2.709	3.461	1.260	1.801	2.147	2.821	3.604	1.291	1.847	2.200	2.892	3.694	1.354	1.936	2.307	3.032	3.873
126	1.209	1.729	2.060	2.708	3.459	1.259	1.800	2.145	2.819	3.601	1.290	1.845	2.198	2.889	3.690	1.352	1.934	2.304	3.028	3.868
128	1.209	1.728	2.060	2.707	3.458	1.258	1.799	2.143	2.816	3.598	1.289	1.843	2.196	2.886	3.686	1.350	1.931	2.301	3.024	3.862
130	1.208	1.728	2.059	2.705	3.456	1.257	1.797	2.141	2.814	3.595	1.288	1.841	2.194	2.883	3.683	1.349	1.928	2.298	3.019	3.857
132	1.208	1.727	2.058	2.704	3.455	1.256	1.796	2.140	2.812	3.592	1.286	1.839	2.192	2.880	3.679	1.347	1.926	2.295	3.015	3.852
134	1.207	1.726	2.057	2.703	3.453	1.255	1.795	2.138	2.810	3.590	1.285	1.838	2.190	2.878	3.676	1.345	1.923	2.292	3.012	3.847
136	1.207	1.725	2.056	2.702	3.452	1.254	1.793	2.137	2.808	3.587	1.284	1.836	2.188	2.875	3.673	1.343	1.921	2.289	3.008	3.842
138	1.206	1.725	2.055	2.701	3.450	1.253	1.792	2.135	2.806	3.585	1.283	1.834	2.186	2.873	3.669	1.342	1.918	2.286	3.004	3.837
140	1.206	1.724	2.054	2.700	3.449	1.252	1.791	2.134	2.804	3.582	1.282	1.833	2.184	2.870	3.666	1.340	1.916	2.283	3.000	3.833
142	1.205	1.723	2.054	2.699	3.448	1.252	1.790	2.132	2.802	3.580	1.281	1.831	2.182	2.868	3.663	1.338	1.914	2.280	2.997	3.828
144	1.205	1.723	2.053	2.698	3.446	1.251	1.788	2.131	2.801	3.578	1.280	1.830	2.180	2.865	3.660	1.337	1.912	2.278	2.993	3.824
146	1.204	1.722	2.052	2.697	3.445	1.250	1.787	2.130	2.799	3.575	1.279	1.828	2.178	2.863	3.657	1.335	1.909	2.275	2.990	3.820
148	1.204	1.722	2.051	2.696	3.444	1.249	1.786	2.128	2.797	3.573	1.278	1.827	2.177	2.861	3.654	1.334	1.907	2.273	2.987	3.815
150	1.204	1.721	2.051	2.695	3.443	1.248	1.785	2.127	2.795	3.571	1.277	1.825	2.175	2.859	3.652	1.332	1.905	2.270	2.983	3.811
152	1.203	1.720	2.050	2.694	3.441	1.248	1.784	2.126	2.794	3.569	1.276	1.824	2.173	2.856	3.649	1.331	1.903	2.268	2.980	3.807
154	1.203	1.720	2.049	2.693	3.440	1.247	1.783	2.125	2.792	3.567	1.275	1.823	2.172	2.854	3.646	1.330	1.901	2.265	2.977	3.803
156	1.202	1.719	2.049	2.692	3.439	1.246	1.782	2.123	2.791	3.565	1.274	1.821	2.170	2.852	3.644	1.328	1.899	2.263	2.974	3.799
158	1.202	1.719	2.048	2.691	3.438	1.246	1.781	2.122	2.789	3.563	1.273	1.820	2.169	2.850	3.641	1.327	1.897	2.261	2.971	3.796
160	1.202	1.718	2.047	2.691	3.437	1.245	1.780	2.121	2.787	3.561	1.272	1.819	2.167	2.848	3.638	1.326	1.896	2.259	2.968	3.792
162	1.201	1.718	2.047	2.690	3.436	1.244	1.779	2.120	2.786	3.559	1.271	1.818	2.166	2.846	3.636	1.324	1.894	2.256	2.965	3.788
164	1.201	1.717	2.046	2.689	3.435	1.244	1.778	2.119	2.785	3.557	1.270	1.816	2.164	2.844	3.634	1.323	1.892	2.254	2.963	3.785
166	1.201	1.717	2.045	2.688	3.434	1.243	1.777	2.118	2.783	3.555	1.269	1.815	2.163	2.843	3.631	1.322	1.890	2.252	2.960	3.781
168	1.200	1.716	2.045	2.687	3.433	1.242	1.776	2.117	2.782	3.553	1.269	1.814	2.162	2.841	3.629	1.321	1.888	2.250	2.957	3.778
170	1.200	1.716	2.044	2.687	3.432	1.242	1.775	2.116	2.780	3.552	1.268	1.813	2.160	2.839	3.627	1.320	1.887	2.248	2.955	3.774

	γ = 0.75					γ = 0.90					γ = 0.95					γ = 0.99				
N/P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
172	1.199	1.715	2.044	2.686	3.431	1.241	1.775	2.115	2.779	3.550	1.267	1.812	2.159	2.837	3.624	1.318	1.885	2.246	2.952	3.771
174	1.199	1.715	2.043	2.685	3.430	1.240	1.774	2.114	2.778	3.548	1.266	1.811	2.158	2.835	3.622	1.317	1.884	2.244	2.950	3.768
176	1.199	1.714	2.043	2.684	3.429	1.240	1.773	2.113	2.776	3.547	1.266	1.810	2.156	2.834	3.620	1.316	1.882	2.243	2.947	3.765
178	1.199	1.714	2.042	2.684	3.428	1.239	1.772	2.112	2.775	3.545	1.265	1.809	2.155	2.832	3.618	1.315	1.880	2.241	2.945	3.762
180	1.198	1.713	2.042	2.683	3.427	1.239	1.771	2.111	2.774	3.543	1.264	1.808	2.154	2.831	3.616	1.314	1.879	2.239	2.942	3.759
185	1.197	1.712	2.040	2.681	3.425	1.237	1.769	2.108	2.771	3.539	1.262	1.805	2.151	2.827	3.611	1.311	1.875	2.234	2.937	3.751
190	1.197	1.711	2.039	2.680	3.423	1.236	1.767	2.106	2.768	3.536	1.261	1.803	2.148	2.823	3.606	1.309	1.872	2.230	2.931	3.744
195	1.196	1.710	2.038	2.678	3.421	1.235	1.766	2.104	2.765	3.532	1.259	1.800	2.145	2.819	3.601	1.307	1.868	2.226	2.926	3.738
200	1.195	1.709	2.037	2.677	3.419	1.234	1.764	2.102	2.762	3.529	1.258	1.798	2.143	2.816	3.597	1.304	1.865	2.222	2.921	3.731
205	1.195	1.708	2.036	2.675	3.418	1.233	1.762	2.100	2.760	3.526	1.256	1.796	2.140	2.812	3.593	1.302	1.862	2.219	2.916	3.725
210	1.194	1.708	2.035	2.674	3.416	1.231	1.761	2.098	2.757	3.522	1.255	1.794	2.138	2.809	3.589	1.300	1.859	2.215	2.911	3.719
215	1.194	1.707	2.034	2.673	3.414	1.230	1.759	2.096	2.755	3.519	1.253	1.792	2.135	2.806	3.585	1.298	1.856	2.212	2.907	3.713
220	1.193	1.706	2.033	2.671	3.413	1.229	1.758	2.095	2.753	3.516	1.252	1.790	2.133	2.803	3.581	1.296	1.854	2.209	2.903	3.708
225	1.192	1.705	2.032	2.670	3.411	1.228	1.756	2.093	2.750	3.514	1.251	1.788	2.131	2.800	3.577	1.294	1.851	2.205	2.898	3.703
230	1.192	1.704	2.031	2.669	3.409	1.227	1.755	2.091	2.748	3.511	1.249	1.787	2.129	2.798	3.574	1.293	1.848	2.202	2.894	3.697
235	1.191	1.704	2.030	2.668	3.408	1.226	1.754	2.090	2.746	3.508	1.248	1.785	2.127	2.795	3.571	1.291	1.846	2.199	2.890	3.692
240	1.191	1.703	2.029	2.667	3.407	1.226	1.752	2.088	2.744	3.506	1.247	1.783	2.125	2.792	3.567	1.289	1.843	2.197	2.887	3.688
245	1.190	1.702	2.028	2.666	3.405	1.225	1.751	2.087	2.742	3.503	1.246	1.782	2.123	2.790	3.564	1.288	1.841	2.194	2.883	3.683
250	1.190	1.702	2.028	2.665	2.404	1.224	1.750	2.085	2.740	3.501	1.245	1.780	2.121	2.788	3.561	1.286	1.839	2.191	2.880	3.678
255	1.190	1.701	2.027	2.664	3.403	1.223	1.749	2.084	2.739	3.499	1.244	1.779	2.119	2.785	3.558	1.284	1.837	2.189	2.876	3.674
260	1.189	1.700	2.026	2.663	3.401	1.222	1.748	2.083	2.737	3.496	1.243	1.777	2.118	2.783	3.555	1.283	1.835	2.186	2.873	3.670
265	1.189	1.700	2.025	2.662	3.400	1.222	1.747	2.081	2.735	3.494	1.242	1.776	2.116	2.781	3.552	1.282	1.833	2.184	2.870	3.666
270	1.188	1.699	2.025	2.661	3.399	1.221	1.746	2.080	2.734	3.492	1.241	1.774	2.114	2.779	3.550	1.280	1.831	2.181	2.867	3.662
275	1.188	1.699	2.024	2.660	3.398	1.220	1.745	2.079	2.732	3.490	1.240	1.773	2.113	2.777	3.547	1.279	1.829	2.179	2.864	3.658
280	1.188	1.698	2.023	2.659	3.397	1.219	1.744	2.078	2.730	3.488	1.239	1.772	2.111	2.775	3.544	1.278	1.827	2.177	2.861	3.655
285	1.187	1.698	2.023	2.658	3.396	1.219	1.743	2.076	2.729	3.486	1.238	1.771	2.110	2.773	3.542	1.276	1.825	2.175	2.858	3.651
290	1.187	1.697	2.022	2.658	3.395	1.218	1.742	2.075	2.727	3.484	1.237	1.769	2.108	2.771	3.540	1.275	1.823	2.173	2.855	3.647
295	1.186	1.697	2.022	2.657	3.394	1.217	1.741	2.074	2.726	3.482	1.237	1.768	2.107	2.769	3.537	1.274	1.822	2.170	2.853	3.644
300	1.186	1.696	2.021	2.656	3.393	1.217	1.740	2.073	2.725	3.481	1.236	1.767	2.106	2.767	3.535	1.273	1.820	2.169	2.850	3.641
310	1.185	1.695	2.020	2.655	3.391	1.216	1.738	2.071	2.722	3.477	1.234	1.765	2.103	2.764	3.531	1.271	1.817	2.165	2.845	3.634
320	1.185	1.694	2.019	2.653	3.389	1.215	1.737	2.069	2.719	3.474	1.233	1.763	2.100	2.760	3.526	1.268	1.814	2.161	2.840	3.628
330	1.184	1.693	2.018	2.652	3.388	1.213	1.735	2.067	2.717	3.471	1.231	1.761	2.098	2.757	3.522	1.266	1.811	2.158	2.836	3.623
340	1.184	1.693	2.017	2.651	3.386	1.212	1.734	2.066	2.715	3.468	1.230	1.759	2.096	2.754	3.519	1.265	1.808	2.154	2.831	3.617
350	1.183	1.692	2.016	2.649	3.384	1.211	1.732	2.064	2.713	3.465	1.229	1.757	2.094	2.752	3.515	1.263	1.805	2.151	2.827	3.612
360	1.183	1.691	2.015	2.648	3.383	1.210	1.731	2.062	2.710	3.463	1.228	1.755	2.092	2.749	3.512	1.261	1.803	2.148	2.823	3.607

	γ = 0.75					γ = 0.90					γ = 0.95					γ = 0.99				
N/P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
370	1.182	1.690	2.014	2.647	3.382	1.210	1.730	2.061	2.708	3.460	1.227	1.754	2.090	2.746	3.508	1.259	1.801	2.146	2.820	3.602
380	1.182	1.690	2.013	2.646	3.380	1.209	1.728	2.059	2.707	3.458	1.225	1.752	2.088	2.744	3.505	1.258	1.798	2.143	2.816	3.598
390	1.181	1.689	2.013	2.645	3.379	1.208	1.727	2.058	2.705	3.455	1.224	1.751	2.086	2.742	3.502	1.256	1.796	2.140	2.813	3.593
400	1.181	1.688	2.012	2.644	3.378	1.207	1.726	2.057	2.703	3.453	1.223	1.749	2.084	2.739	3.499	1.255	1.794	2.138	2.809	3.589
425	1.180	1.687	2.010	2.642	3.375	1.205	1.723	2.054	2.699	3.448	1.221	1.746	2.080	2.734	3.492	1.251	1.789	2.132	2.802	3.579
450	1.179	1.686	2.009	2.640	3.372	1.204	1.721	2.051	2.695	3.443	1.219	1.743	2.077	2.729	3.486	1.248	1.785	2.127	2.795	3.570
475	1.178	1.685	2.007	2.638	3.370	1.202	1.719	2.048	2.692	3.438	1.217	1.740	2.073	2.725	3.481	1.245	1.781	2.122	2.788	3.562
500	1.177	1.683	2.006	2.636	3.368	1.201	1.717	2.046	2.689	3.434	1.215	1.737	2.070	2.721	3.475	1.243	1.777	2.117	2.783	3.555
525	1.177	1.682	2.005	2.635	3.366	1.199	1.715	2.043	2.686	3.431	1.213	1.735	2.067	2.717	3.471	1.240	1.773	2.113	2.772	3.548
550	1.176	1.681	2.004	2.633	3.364	1.198	1.713	2.041	2.683	3.427	1.212	1.733	2.065	2.713	3.466	1.238	1.770	2.109	2.772	3.541
575	1.175	1.681	2.003	2.632	3.362	1.197	1.712	2.039	2.680	3.424	1.210	1.731	2.062	2.710	3.462	1.236	1.767	2.106	2.767	3.535
600	1.175	1.680	2.002	2.631	3.360	1.196	1.710	2.038	2.678	3.421	1.209	1.729	2.060	2.707	3.458	1.234	1.764	2.102	2.763	3.530
625	1.174	1.679	2.001	2.629	3.359	1.195	1.709	2.036	2.676	3.418	1.208	1.727	2.058	2.704	3.455	1.232	1.762	2.099	2.759	3.525
650	1.174	1.678	2.000	2.628	3.357	1.194	1.707	2.034	2.674	3.416	1.207	1.725	2.056	2.702	3.451	1.230	1.759	2.096	2.755	3.520
675	1.173	1.678	1.999	2.627	3.356	1.193	1.706	2.033	2.672	3.413	1.205	1.724	2.054	2.699	3.448	1.229	1.757	2.094	2.752	3.515
700	1.173	1.677	1.998	2.626	3.355	1.192	1.705	2.032	2.670	3.411	1.204	1.722	2.052	2.697	3.445	1.227	1.755	2.091	2.748	3.511
725	1.172	1.676	1.998	2.625	3.354	1.192	1.704	2.030	2.668	3.408	1.203	1.721	2.050	2.694	3.442	1.226	1.753	2.089	2.745	3.507
750	1.172	1.676	1.997	2.624	3.352	1.191	1.703	2.029	2.667	3.406	1.202	1.719	2.049	2.692	3.439	1.225	1.751	2.086	2.742	3.503
800	1.171	1.675	1.996	2.623	3.350	1.189	1.701	2.027	2.663	3.402	1.201	1.717	2.046	2.688	3.434	1.222	1.747	2.082	2.736	3.495
850	1.171	1.674	1.994	2.621	3.348	1.188	1.699	2.025	2.661	3.399	1.199	1.714	2.043	2.685	3.430	1.220	1.744	2.078	2.731	3.489
900	1.170	1.673	1.993	2.620	3.347	1.187	1.697	2.023	2.658	3.396	1.198	1.712	2.040	2.682	3.426	1.218	1.741	2.075	2.726	3.483
950	1.169	1.672	1.992	2.619	3.345	1.186	1.696	2.021	2.656	3.393	1.196	1.710	2.038	2.679	3.422	1.216	1.738	2.071	2.722	3.477
1000	1.169	1.671	1.992	2.617	3.344	1.185	1.695	2.019	2.654	3.390	1.195	1.709	2.036	2.676	3.418	1.214	1.736	2.068	2.718	3.472
	1.150	1.645	1.960	2.576	3.291	1.150	1.645	1.960	2.576	3.291	1.150	1.645	1.960	2.576	3.291	1.150	1.645	1.960	2.576	3.291

Rauscher, H. Michael.
The microcomputer scientific software series 4: testing prediction accuracy. Gen. Tech. Rep. NC-107. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 19 p.

A computer program, ATEST, is described in this combination user's guide/programmer's manual. ATEST provides users with an efficient and convenient tool to test the accuracy of predictors. As input ATEST requires observed-predicted data pairs. The output reports the two components of accuracy, bias and precision.

KEY WORDS: Statistics, model validation, microcomputers, jackknife statistic, confidence intervals.


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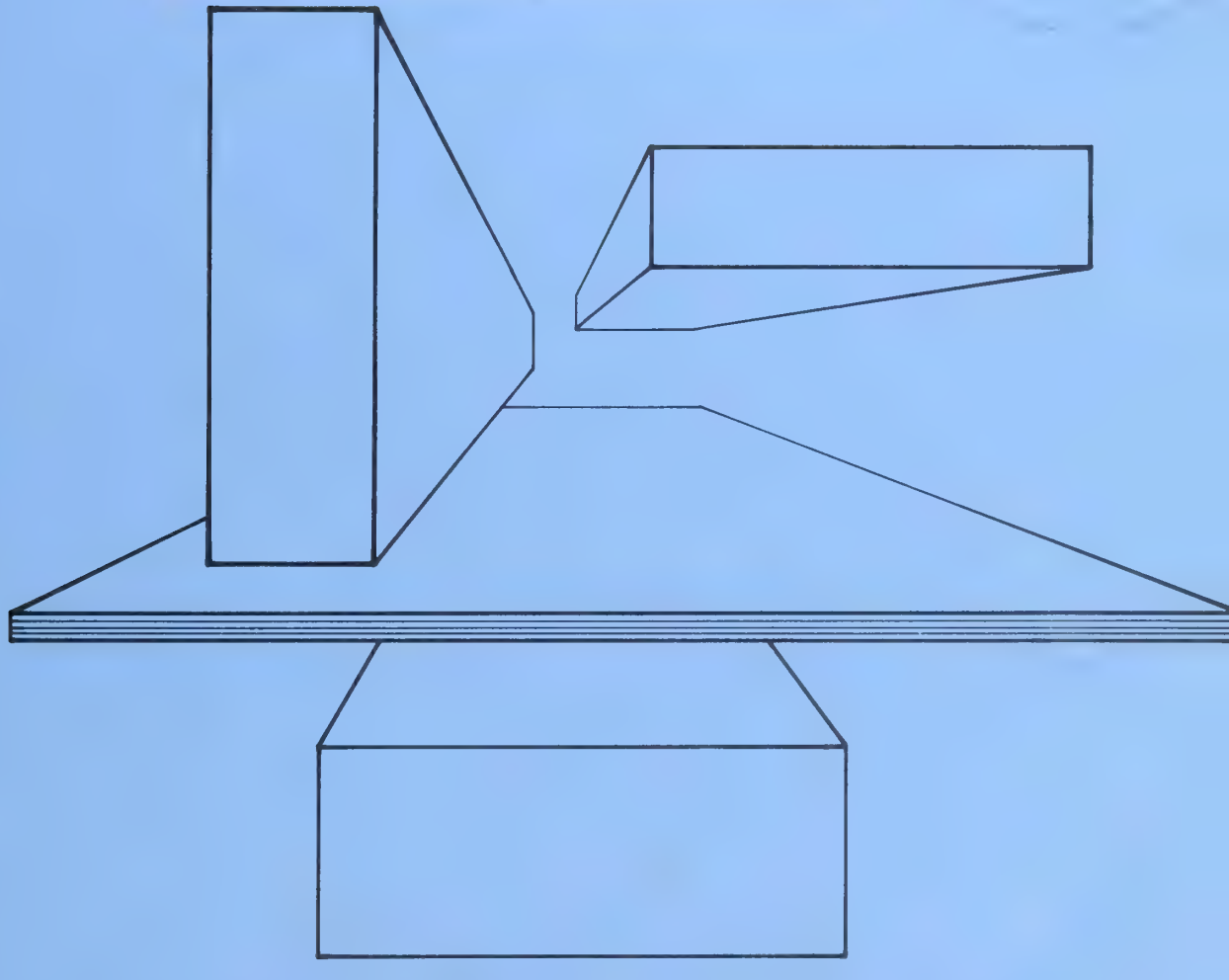
Forest Service

North Central Forest Experiment Station

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Production and Consumption of Major Wood Products in the Lake States: Perspectives and Trends

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CONTENTS

	Page
The Lake States Region	1
Forest Planning Information	1
Regional Timber Resources	2
Forest Land	2
Timber Resources	2
Growth and Removals	3
Supply-demand-consumption Relations	3
Regional Timber Demand	4
Estimating Regional Timber Product Consumption	4
Derived Demand	4
Definitions	4
Data Sources	5
Product Flow Concepts	5
Use-factor Approach	6
Paper and Board	7
Woodpulp and Wastepaper	7
Pulpwood	8
Particleboard Effect	8
Future Consumption and Exports	8
Lumber	9
Lumber Consumption and Production	9
Saw Logs	10
Future Consumption	10
Plywood and Veneer	11
Plywood and Veneer Consumption and Production	11
Veneer Logs	11
Future Consumption and Exports	12
Particleboard	12
Particleboard Consumption and Production	12
Future Consumption and Exports	13
Fuelwood	13
Fuelwood Consumption	13
Fuelwood Production	14
Future Consumption and Exports	14
Summary and Conclusions	14
Timber Resources	14
Paper and Board	15
Lumber	15
Plywood and Veneer	15
Particleboard	15
Fuelwood	16
Policy Implications	16
Research and Information Needs	16
Literature Cited	17
Glossary	19
Appendix	21
Figures	21
Tables	22

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PRODUCTION AND CONSUMPTION OF MAJOR WOOD PRODUCTS IN THE LAKE STATES: PERSPECTIVES AND TRENDS

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THE LAKE STATES REGION

Michigan, Minnesota, and Wisconsin comprise the Lake States, a region covering 191,000 square miles (5 percent of the total U.S. land area). More than 18 million people (8 percent of the total U.S. population) live within the region, most residing in the region's large southern metropolitan areas. Agriculture plays a major role in the southern part of the region, growing in significance toward the west. Timber production activities span the region's northern reaches, with associated wood products manufacturing occurring throughout the central and southern portions. Mining, primarily iron, concentrates in northeastern Minnesota yet stretches across northern Wisconsin and Michigan's Upper Peninsula. The region's expansiveness, significant population and important economic activities make the Lake States a vital part of the nation's political economy.

The recession of the early 1980's brought extraordinary economic hardship to the Lake States. Michigan, with its huge manufacturing sector, was particularly stricken. Unemployment in the State rose from 6.9 percent in 1978 to 15.5 percent in 1982, compared to a 1982 national unemployment rate of 9.7 percent (U.S. Department of Commerce, Bureau of the Census 1984). On average, Wisconsin and Minnesota fared slightly better; however, some areas, notably Minnesota's Iron Range, experienced unemployment rates approaching 20 percent. Many believed that the fundamental structure of some regional industries, especially mining and automobile manufacturing, was changing and that prospects for future employment in such industries were bleak. Each state undertook massive efforts to provide assistance and retraining programs for the unemployed in an effort to curb economic distress and stem the outflow of labor. The forest products sector, which directly employed more than 180 thousand workers in the region, was given particular attention since it had weathered the recession relatively well and the region contained vast and underutilized timber resources. Forestry officials within the region sought increased cooperation as a means of identifying new opportunities for development within the forest products sector.

FOREST PLANNING INFORMATION

State and federal forestry agencies within the Lake States have been involved with comprehensive forest planning activities since the early 1970's. These planning efforts intensified during the early 1980's, largely in response to the Forest and Rangeland Renewable Resources Planning Act, as amended by the National Forest Management Act of 1976. Forest resource managers and planners developed a common concern during this period about the quality, quantity and form of information available for planning purposes (Lewis and Ellefson 1983). The lack of adequate information presented a significant barrier to the development of long-term timber management strategies necessary to promote growth and stability in the Lake States forest products sector. Five problems were of special concern:

- Incomplete timber resource requirement projections for several geographic areas within the Lake States;
- Inconsistent forest resource plans among several government agencies, and between geographic areas;

- Misallocation of resources in attempting to efficiently meet forest resource requirements;
- Duplication of effort and costs in making various, limited timber supply and demand projections; and
- An inability to identify and resolve regional problems.

In an attempt to address some of these difficulties, a unique cooperative effort was undertaken. The Lake States Planning Coordination Committee initiated the effort. Financial support was provided by state forestry agencies in Minnesota, Michigan, and Wisconsin; USDA Forest Service National Forest Administration; USDA Forest Service Research; and the Department of Forest Resources, University of Minnesota[1]. The objectives of the cooperative agreement were to:

- Develop reliable estimates of current primary and secondary wood product production and consumption in the Lake States;
- Identify major issues related to the ability of Lake States timber resources to meet future timber requirements;
- Improve the consistency, reliability and availability of information pertaining to Lake States timber supply and demand; and
- Promote cooperation among the Lake States in addressing regional forestry problems and opportunities.

In pursuing these objectives, the perspective of forest resource managers and planners was maintained. The focus was on types of information necessary to develop workable strategies for meeting long-term timber resource demands in the Lake States. Relevent economic, technological and demographic factors were considered and characteristics of the region's timber resources explored in order to identify significant issues and opportunities.

REGIONAL TIMBER RESOURCES

Forest Land

Area

The Lake States is one of the nation's most densely forested regions, second only to New England. The 45.5 million acres of commercial forest land in the region, which represent nearly 10 percent of the national total, are distributed fairly evenly among the three states: Michigan, 17.5 million acres; Minnesota, 13.5 million acres; and Wisconsin, 14.5 million acres. Minnesota and Michigan have experienced significant reductions in commercial forest land since 1952. Minnesota's commercial forest land declined about 11 percent, largely as a result of the creation of the Voyageurs National Park and the expansion of the Boundary Waters Canoe Area (Jakes 1980a). Michigan's commercial forest land declined about 7 percent, due primarily to urban and related development, much of which occurred in the state's southern lower peninsula (Spencer 1983). Wisconsin's commercial forest land held fairly steady between 1952 and 1968 (Spencer and Thorne 1972). The state's 1983 forest survey, however, shows that commercial forest land increased by 1.5 percent since 1968 due to farmland in the southern part of the state reverting back to forest land. Despite Wisconsin's promising reversal, the trend toward a declining commercial forest land base remains an important forestry issue in the Lake States.

Ownership

Nearly half of the commercial forest land in the Lake States is publicly owned, with state and county ownership accounting for about 26 percent. This relatively high proportion of non-federal public forest land ownership is unique to the region and represents an opportunity for state and county forestry agencies to largely determine the future of the Lake States' forest.

Timber Resources

Forest Types

The region's forests can be characterized by six major forest types. Aspen-birch dominates the region, covering 32 percent of the commercial forest land, followed by maple-beech-birch (24 percent), spruce-fir (15 percent), oak-hickory (12 percent), white-red-jack pine (8 percent), and elm-ash-cottonwood (7 percent). About two percent of the region's commercial forest land is classified as nonstocked. There are some distinct differences between the states in the region. Minnesota is heavily dominated by aspen-birch (50 percent) while maple-beech-birch predominates in Michigan (35 percent). Wisconsin is dominated by roughly equal proportions of these two forest types.

[1]*Concurrent with this project was a study by the Conservation Foundation on forest policies in the Lake States which also encourages regional cooperation and coordination (Shands and Dawson 1984).*

Timber Volume

Hardwoods account for nearly three-fourths of the growing-stock volume in the region. The distribution of growing-stock volume among ownership classes is closely related to the distribution of commercial forest land. The proportion of hardwoods, however, varies among ownership classes, being slightly higher for private nonindustrial owners (about 80 percent) than for federal and state ownerships (about 60 percent).

Productivity

The average growing-stock volume per acre is relatively consistent across ownership classes in the Lake States. The regional average of 921 cubic feet per acre is low when compared to the national average of 1,466 cubic feet, partially reflecting small timber sizes and low levels of management intensity in the region (Jakes 1980a). But also, the average site class (i.e., a measure of potential site productivity assuming fully-stocked natural stands at culmination of mean annual increment) in the region is only 48 cubic feet per acre per year whereas the average site class in the nation is 73 cubic feet per acre per year. This measure suggests that the Lake States may have to overcome the disadvantage of having a less productive forest land base than other regions. However, the region holds the advantage of having greater opportunity to increase timber productivity, especially compared to the South which has nearly achieved its productive potential (Hagler 1983).

Age-Class Distribution

Stands between 40 and 60 years of age dominate commercial forest land in the Lake States and are evenly distributed among the three states. These stand-ages resulted from heavy cutting combined with fire and wind disturbances that occurred in the early part of the 20th century. Because two of the region's major species, aspen and birch, are relatively short-lived, many of the stands are beginning to deteriorate. Such deterioration implies a lost opportunity to utilize existing timber resources and a failure to achieve the physical capability of the land base to produce timber.

The skewed age-class distribution also raises an important and complex question: how can the "wall of wood" now occupying the Lake States forests be effectively utilized without entailing a subsequent decline in timber resource availability? Assumptions about the species composition of the Lake States "third forest" and increased growth rates after harvesting the slow-growing, mature timber carry significant implications.

Size-Class Distribution

The Lake States is the nation's only region dominated by pole-size timber. Forty-five percent of the region's commercial forest land is covered by poletimber, a distribution pattern which is fairly consistent across the three states. Although species composition, stocking levels and age class largely determine size, the size-class distribution pattern in the Lake States also can be attributed to regional timber industries that primarily harvest and process pole-size trees. Whether poletimber or larger-sized timber products should be the focus of the Lake State's third forest represents an important question for the region.

Growth and Removals

Despite an 8 percent reduction in commercial forest land between 1952 and 1977, growing stock volumes of hardwoods and softwoods in the Lake States increased at a faster rate than in any other region of the country (Jakes 1981). These increases were attributable in part to low levels of utilization. In 1977, for example, net annual hardwood growth exceeded removals by nearly 40 percent and softwood growth exceeded removals by 30 percent. Over the past few years, expansion in the pulp and paper industry, rapid growth in the structural particleboard industry and rising consumption of wood for energy have narrowed the gap between growth and removals. For aspen, the species in greatest demand, the gap might have closed completely (Shands and Dawson 1984). However, since a large proportion of the productive potential in the Lake States is not being achieved, there is opportunity to increase production and sustain growth in the timber product industries for some time (USDA Forest Service 1982).

Supply-Demand-Consumption Relations

The terms "timber supply," "timber demand," and "timber consumption" are often loosely used. Supply is sometimes confused with timber volume or growth while demand is misinterpreted as growing-stock removals or timber receipts at the mill gate. Supply and demand are economic variables affected by changes in numerous factors: population, income,

preferences, technology, etc. Timber supply refers to the volume that timber owners would be willing to sell at given stumpage prices at a given place and time. As stumpage prices rise owners presumably would be willing to offer greater volumes for sale. Stumpage price alone does not determine whether a particular timber stand would be made available for purchase. The stand must also be considered "operable" (i.e., logging and transportation costs must also be covered by the purchaser).

Timber demand refers to the volume of timber that users would be willing to purchase at given prices at a given place and time. Rising stumpage prices generally result in reduced timber purchases; however, timber demand is affected by important factors other than stumpage prices (e.g., population and income changes, shifts in the relative prices of final timber products and their substitutes, changes in society's preferences).

Timber consumption is the actual amount of timber which clears the market at a price agreed upon by seller and purchaser. In sum, timber supply, demand and consumption are determined by complex economic relationships and thus must be differentiated from information such as volume, growth, removals and receipts.

Regional Timber Demand

Relative Prices

Changes in relative stumpage prices often represent the driving force behind regional shifts in mill capacity and thus, regional timber demand (USDA Forest Service 1982). This is particularly true for the lumber industry in which stumpage prices represent a large percentage of the final product's selling price. For example, relative stumpage prices were critical factors in the shift of U.S. lumber production from the Pacific Northwest to the South. As competition for timber increases and stumpage prices rise in the South relative to other regions, lumber production may shift again, perhaps back to the Pacific Northwest.

Stumpage prices in the Lake States are relatively low. Furthermore, proximity to large Midwestern markets represents a competitive advantage for the region, particularly with respect to the West but also the South. The wood products industry has responded to these factors by locating several new mills in the region during the past few years. An important question is whether the region is capable of meeting the timber requirements of these and perhaps additional mills without incurring significant stumpage price increases.

Technology

Advances in technology have been critical to renewed interest in the Lake States forest. For example, new harvesting systems have responded to many problems associated with large volumes of pole-size timber; reconstituted board technologies have enabled industries to utilize pole-size timber for structural panel products (e.g., waferboard and oriented strand board); and hardwood species, especially aspen, have become extremely desirable for particleboard products and as a component of the woodpulp mix paper and board production. Other technologies, such as sawing and drying techniques that reduce the warpage in hardwood dimension lumber, are being developed that will continue to enhance the position of the Lake States as a supplier of wood products.

ESTIMATING REGIONAL TIMBER PRODUCT CONSUMPTION

Derived Demand

The traditional approach to estimating timber demand assumes that demand equals the consumption of final timber products (Cardellichio and Veltkamp 1981). This "derived demand" approach will be used in this report. For simplicity and accuracy, however, demand will be referred to as "consumption." In effect, timber products will be traced through their various processing phases to the final or end-use markets in which they are consumed.

Definitions

Timber product categories are difficult to define because of the complex nature of product manufacturing. Mill residues from a sawmill, for example, may be shipped to a pulpmill for pulping. Are they a secondary product of the sawmill or a primary product for the pulpmill? For purposes of this report, primary timber products are defined as roundwood products such as pulpwood, saw logs, veneer logs, and fuelwood. Mill residues are also included since they re-enter the primary-mill processing stage. Like fuelwood, if residues are used as fuel, they are considered both a primary product and a final product.

Secondary timber products are any primary prodcts that undergo further processing. This broad efinition simplifies the complex of processes and roducts involved in timber product manufacturing. or reasons of practicality, however, it is necessary limit the number of secondary products considred. Therefore, four more specific product classificaons will represent secondary products: paper and oard, lumber, particleboard, and plywood and veer. Although these four product classifications ay be relatively specific, problems with definitions main. The most troublesome classification is particeboard. At times particleboard represents a broad nge of products manufactured from wood particles, ch as waferboard, oriented strand board, and edium-density fiberboard (USDA Forest Service 982; U.S. Department of Commerce, Bureau of the ensus, Census of Manufactures series). At other mes it specifies a dry, reconstituted board product sed for industrial purposes, primarily furniture anufacturing (Pennington 1984). For purposes of is report, the broad particleboard definition will be sed for the classification. The narrow particleboard efinition will represent one product within the clasfication. It will be called "industrial particleboard" differentiated from the "structural particleboard" roducts in the classification (see Particleboard secon).

Data Sources

The availability of data on the production and conmption of primary and secondary timber products aries among products. In general, the amount of vailable data is directly related to the perceived nportance of the product to the region at a given me. For example, a very good data series has been aintained for pulpwood because of its significant ntribution to the Lake States economy. By comarison, less data is available for veneer logs and w logs because they hold less economic imporance. In addition, data on saw logs is more difficult obtain due to the large number of small mills that mprise the region's lumber industry.

There is generally more and better data available r primary timber products than for secondary timer products. The USDA Forest Service, North Cenal Forest Experiment Station (NCFES) has been nducting mill surveys for many years, often in connction with state forestry agencies. These surveys epresent a reliable and fairly consistent data series r primary production and consumption.

By comparison, secondary product data comes from multiple sources, is laden with inconsistent industry and product definitions, and often has a questionable degree of reliability. The Bureau of the Census (U.S. Department of Commerce) and the USDA Forest Service are the major sources of secondary product data. However, trade organizations (e.g., the American Paper Institute, American Plywood Association, and National Particleboard Association), and private research organizations (e.g., Data Resources Incorporated, Stanford Research Institute, and Morgan Stanley & Company) also generate such data.

This report relies heavily on data gathered by the USDA Forest Service and Bureau of the Census. Since both of these sources present secondary data within the framework of the Standard Industrial Classification (SIC) system, they are relatively consistent. Although the best available, much of the USDA Forest Service and Bureau of the Census data is subject to large sampling errors and should be approached with some caution[2].

Product Flow Concepts

The flow of primary and secondary timber products can be very complex (fig. 1). Some primary products flow directly to end-use markets (e.g., fuelwood). Most products, however, receive further processing before they reach such markets. Imports and exports of various products occur along the flow, often in perplexing patterns. For example, softwood residues and woodpulp are imported for the region's pulp and paper industry while significant volumes of low-cost red pine remain unused in one part of the region and roundwood pulpwood is being exported from other parts. These patterns could probably be explained given information about transportation costs and trade relationships. Without such information, however, some import and export patterns remain enigmatic.

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[2]*The Bureau of the Census has been underestimating lumber production in the South for some time. This also appears to be true for the Lake States where lumber production estimates by the Bureau of the Census are as much as 25 percent lower than estimates by the North Central Forest Experiment Station for some years, (e.g., Michigan's 1977 lumber production was reported as 350 million board feet by the Bureau of the Census whereas the North Central Forest Experiment Station reported it as 457 million board feet).*

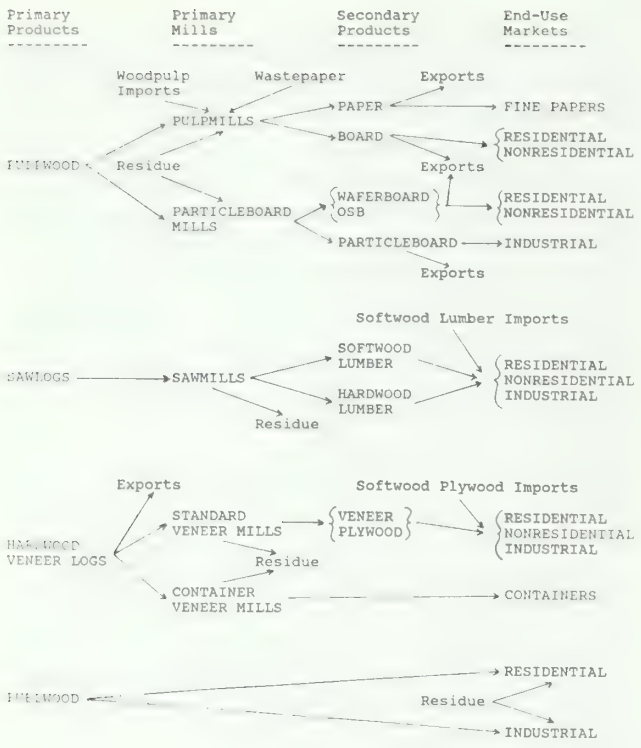


Figure 1.—*Primary and secondary wood product flows in the Lake States.*

Use-Factor Approach

As discussed previously, the demand for primary timber products is derived from the demand for secondary products, which is represented by secondary product consumption. Estimates of secondary product consumption in major end-use markets in the Lake States for this report were determined by the use-factor approach. This approach was first applied to wood product markets in the 1950's and has gained popularity due to advantages over traditional statistical analysis (Cardellichio and Veltkamp 1981).

The use-factor approach begins by identifying the major end-uses or individual markets in which a secondary product is consumed. Associated with each end-use is a "demand indicator" (i.e., an indicator of the level of market activity) and a "use-factor" (i.e., a measure of wood consumed per end-use unit). For example, the demand indicators and use-factors associated with each end-use market for lumber identified in the Lake States are presented in table 1. The product of the demand indicator and the use-factor associated with each market equals the lumber consumption in that market. The sum of the consumption in all markets estimates total lumber consumption in the Lake States.

Because the use-factor approach incorporates the results of major market surveys conducted by the USDA Forest Service, it provides detailed data about individual markets. Such detail, however, introduces some problems. Large sampling errors exist in some of the data and inconsistent industry and product definitions are sometimes difficult to reconcile (Cardellichio and Binkley 1984). As a result, different estimates of the same use-factor sometimes appear. For example, estimates of lumber-use per single-family home in 1977 by Spelter and Phelps (1984), the USDA Forest Service (1982), and Clephane (1982), were 11,970, 11,600, and 10,800 board feet per home, respectively.

Table 1.--Lumber market definitions

End-use market	Demand indicator	Use-factor
Residential construction	Single-family housing Multi-family housing Mobile home shipments	BF/sq. ft. of floor
	Additions & repairs (valuation)	BF/$1977
Nonresidential construction	Nonresidential buildings (valuation)	BF/$1977
Pallets	Pallet production	BF/pallet
Containers and dunnage	Index of all manufacturing (index, 1967 = 1)	BBF/index unit
Furniture	Furniture production index (index, 1967 = 1)	BBF/index unit
Other manufacturing	Index of all manufacturing (index, 1967 = 1)	BBF/index unit

(Adapted from Cardellichio and Binkley 1984.)

National use-factors were used in conjunction with Lake States demand indicators to derive estimates of secondary product consumption in this report. Appropriate state demand indicators were found for some end-use markets; for others, methods were developed to estimate regional shares of national demand indicators. Use-factors and demand indicators, where available, are presented in the appendices in association with the appropriate end-use markets. The use-factor approach was not used to estimate the consumption of paper and board because another per-capita consumption approach was deemed more suitable.

Successful application of the use-factor approach to the Lake States region implies two major assumptions. First, we assumed that the costs and technologies of end-use markets in the Lake States do not differ significantly from the costs and technologies of those same end-use markets in the nation as a whole. For example, this presumes that a hardwood pallet manufactured in the Lake States uses the same amount of hardwood lumber as the average hardwood pallet manufactured in the U.S., or that the amount of plywood used in the Lake States per dollar of expenditure in the residential alteration and repair market is the same as the average amount of plywood used per dollar of expenditure in the same end-use market nationally.

Second, we assumed that regional data sources can serve as demand indicators even though some are not directly comparable to the national demand indicators and others are estimates derived through regional share-analysis of national demand indicators. For example, shipments of mobile homes to the region are assumed to reflect mobile home production in the region. Also, pallet production is assumed to be a regional share of national production, since no regional data exists.

These two assumptions compound the problem of large sampling error which already exists in the national data for certain markets; however, the use-factor approach still provides a logical and informative method for estimating secondary product consumption. Moreover, new market information from surveys or knowledgeable individuals may easily be incorporated into the estimates. Therefore, the estimates can be considered to be as reliable as the best information available for any given market, and, in aggregate, as the sum of the best existing information.

PAPER AND BOARD

The paper and board industry in the Lake States began developing in the early 1900's and grew while the region's lumber industry declined[3]. Today it is the region's major wood products industry, employing over 100,000 workers and utilizing more than twice as much roundwood as all other regional wood products industries combined.

The Lake States paper industry has found an especially good market niche in the production of high-quality paper for writing, magazines and books (Lothner and Skok 1977). Domestic markets for such paper products have grown rapidly as personal disposable incomes have increased. Future prospects for growth appear strong both domestically and in export markets[4].

Paper production in the region increased from 2.8 million tons in 1960 to 4.2 million tons in 1975 while board production held relatively steady. The increasing ratio of paper to board production represents the rising significance of paper to the region. In 1977 the Lake States accounted for 16 percent of the nation's total paper production and claimed the nation's number one paper-producing state (Wisconsin).

Total paper and board production in the region rose from 4.9 million tons to 7.8 million tons between 1960 and 1980 while estimates of paper and board consumption during the same period rose from 3.3 to 5.5 million tons. The 1.5 to 2 million-ton gap between production and consumption represents net exports of paper and board to markets outside of the Lake States. Although not precisely known, these export markets are probably located in Midwest and Northeast publishing centers.

Woodpulp and Wastepaper

The manufacture of paper and board requires the consumption of fibrous material, generally in the form of woodpulp or waste-paper. In 1980, 38 woodpulp mills in the Lake States produced 3.5 million

[3]*Paper and board is defined to represent all grades of paper, all grades of paperboard, wet machine board, and construction paper and board, including insulation board and hardboard (U.S. Department of Commerce, Bureau of the Census, Current Industrial Report, Series M26A).*

[4]*United States exports of book paper and fine paper to Canada and Latin America have been increasing rapidly in recent years (USDA Forest Service 1982).*

form of woodpulp or waste-paper. In 1980, 38 woodpulp mills in the Lake States produced 3.5 million tons of woodpulp; an additional 1.7 million tons were imported to meet woodpulp requirements for that year (Blyth and Smith 1982). In total, an estimated 5.2 million tons of woodpulp plus 1.8 million tons of wastepaper were consumed by the region in the manufacture of 7.8 million tons of paper and board. The Lake States has relied upon significant woodpulp imports for at least the last 20 years, the majority of which originated in Canada.

Pulpwood

In 1982, 38 pulpmills and 8 particleboard mills received 5.66 million cords of pulpwood in the form of roundwood or residue (Blyth and Smith 1984a)[5]. Of this total, 5.52 million cords were produced in the Lake States; the remaining volume (mostly softwood residues) was imported from other states (primarily western states) and Canada[6].

Pulpwood receipts by Lake States mills consistently exceeded pulpwood production between 1960 and 1980, although the gap narrowed in the latter years. The composition of the region's imports, however, changed during this period. In the earlier years, roundwood pulpwood accounted for the majority while in the latter years residues comprised virtually all of the imports. The source of these imports also changed during the period. In the earlier years, the majority came from Canada whereas western states (e.g., South Dakota and Wyoming) provided most imports in the latter years.

The reliance on pulpwood imports, although diminishing in recent years, could represent a concern to the Lake States, particularly Wisconsin. If the supply of softwood residues from the West were to diminish with the advent of more efficient sawmill techniques and reduced lumber production, Lake States pulpmills would have to seek new softwood sources, or perhaps hardwood substitutes, in order to meet their requirements. Whether the forests of the region can physically produce such increases at competitive prices is subject to speculation.

Aspen is the region's key pulpwood species, although there is a significant upward trend in production and mill receipts of other hardwoods such as paper birch, hard and soft maple and red oak. The region produces all of the hardwood roundwood it uses as pulpwood. For many of the last twenty years, softwood roundwood has been imported, although such imports appear to be declining. Ponderosa pine from western states and jack pine from Canada have been the significant "hard pine" imports, while Canadian spruce has been the major "other softwood" import. In recent years, Lake States production of both hard pine and other softwoods has surpassed mill receipts in the region. However, hard pine receipts have continued to rise while other softwood receipts appear to be declining, suggesting a regional preference for the former.

Particleboard Effect

The eight particleboard mills active in the region used 675 thousand cords of pulpwood (mostly aspen) in 1982 for the production of 780 million square feet of particleboard (Blyth and Smith 1984a)[7]. The growth of the particleboard industry, primarily structural particleboard (e.g., waferboard and oriented strand board), has been dramatic in the past five years. In 1983, Lake States mills became the leading producers of waferboard and oriented strand board in the nation and in the world. The industry's future appears bright, although questions remain about the ability of Lake States forests, especially aspen resources, to sustain continued growth in the particleboard industry as well as the paper and board industry.

Future Consumption and Exports

The future consumption of Lake States paper and board products will depend upon trends in national and international markets as well as the ability of the Lake States to compete with other regions in providing these products. Assumptions about population growth, economic activity and the character of the region's timber resources and industry become critical. In general, national and international markets for high-quality paper are expected to continue

[5]*Particleboard mills are defined as those manufacturing industrial particleboard, waferboard, oriented strand board and other composition boards.*

[6]*For simplicity, it is assumed that pulpwood exports from the Lake States are insignificant. Thus, pulpwood receipts by Lake States' mills minus pulpwood production within the region represents net pulpwood imports.*

[7]*Particleboard pulpwood requirements have been included in pulpwood data since 1979 (Blyth and Smith 1981). Therefore, an adjustment must be made to determine the amount of pulpwood produced strictly for pulpmills. In 1982, the revised pulpwood receipts at pulpmills would be approximately 5 million cords; almost the entire reduction would be composed of aspen receipts.*

growing at rates several points above the Gross National Product (Pulp and Paper 1982). The potential for Lake States paper production to grow with these markets appears to be great. Prospects for competing with other regions in the nation also appear good. Although the region's paper and board industry significantly depends on imports of both woodpulp and softwood residue and faces increasing competition from the particleboard industry for the aspen resource, several factors support the assumption that the industry will continue to grow and be in a favorable position to compete with other regions:

- Relative proximity to publishing centers in the Midwest and Northeast and to international ports;
- Extensive 38-mill infrastructure in a capital intensive industry;
- Stumpage costs representing only a small percentage of the selling price of paper and board products, i.e., rising stumpage prices have relatively little effect on stumpage demand;
- History of cost-saving technical improvements at all levels of processing, as exemplified by the increased use of low-cost hardwoods; and
- Vast timber resource base with a significant potential for gains in productivity.

LUMBER

During the late 19th century, the Lake States led the nation in lumber production. White pine, red pine, and other softwoods were the dominant species. After steady decline to the 1930's, the region's lumber industry began to grow once more. This time, however, production consisted primarily of hardwoods, since the Lake States "second forest" was a hardwood forest. Of the 889 primary wood-using mills in the Lake States in 1975, 775 were sawmills most of which were small (i.e., they used only half as much roundwood as the region's 41 active pulpmills) (Blyth *et al*. 1980). Saw log production has been increasing in recent years, and, as more of the region's poletimber moves into the sawtimber size class, production should continue to rise. Lumber consumption in the region, however, will largely determine the level of saw log production.

Lumber Consumption and Production

More than 1.5 billion board feet of softwood lumber and nearly 0.8 billion board feet of hardwood lumber are consumed in the region's major end-use markets each year (table 2) (Spelter and Phelps)[8].

Table 2.--Lake States lumber consumption by end use

(In million board feet)

	1973	1977	1981
Softwoods			
Residential			
Single-family	974.8	1,071.5	329.9
Multi-family	269.8	206.2	87.6
Mobile homes	82.4	47.1	32.9
Alterations and repairs	NA	NA	63.3
Nonresidential buildings	NA	NA	63.4
Industrial			
Pallets	124.0	150.4	153.0
Containers and dunnage	102.5	70.2	69.6
Furniture	108.9	139.5	158.7
Other mfg.	114.5	117.7	125.2
Total	1,776.9	1,802.6	1,083.6
Hardwoods			
Residential			
Single-family	41.8	38.3	12.0
Multi-family	4.9	3.0	.8
Mobile homes	3.4	1.8	1.2
Nonresidential buildings	NA	NA	10.6
Industrial			
Pallets	310.0	355.0	384.0
Containers and dunnage	119.6	111.3	117.3
Furniture	203.4	203.8	211.6
Other mfg.	63.3	54.0	54.6
Total	746.4	767.2	792.1

Softwood lumber consumption depends upon residential construction markets, primarily single-family home construction. It is therefore subject to great fluctuation, such as the 40 percent decline seen during the 1981 building recession. Hardwood lumber consumption, on the other hand, depends on industrial markets which have shown steady growth. Pallet manufacturing represents about one-half of the region's industrial wood consumption.

Consumption estimates are more reliable for some markets than others because of statistical errors in the national use-factor estimates and the method of applying use-factors to the region. Estimates of lumber consumption in single- and multi-family home construction, for example, are relatively secure because both the national use-factors and the regional

[8]*Spelter and Phelps (1984) estimate that the end-use markets included here represent about 75 percent of total softwood lumber consumption and 85 percent of total hardwood lumber consumption in the nation. Because it is reasonable to assume that similar proportions apply for the region, consumption estimates for the region probably understate actual consumption.*

data to which they were applied are fairly reliable. Lumber-use estimates in alteration and repair markets, on the other hand, may be questionable because national use-factor estimates have a high degree of uncertainty and regional share estimates had to be developed in order to apply national use-factors.

Lumber consumption estimates for industrial end-use markets are subject to considerable uncertainty as well, primarily because of the need to estimate regional shares of national manufacturing. Inconsistent industry and product definitions also introduce error into regional estimates of individual markets. When individual market estimates are aggregated, however, the errors are probably reduced.

Hardwood lumber production in the region roughly equals consumption, whereas softwood lumber production represents only a small portion (10 to 15 percent) of total regional consumption in the region. This suggests that hardwood lumber consumed in the region is largely produced by Lake States sawmills. Softwood lumber consumed in the region, on the other hand, is composed primarily of imports from Canada and from southern and western states.

Saw Logs

In 1980, the Lake States produced more than 1.1 billion board feet of saw logs, three-quarters of which was hardwoods. Aspen was the dominant species with red oak and hard maple being significant other species. Aspen was used primarily in pallets, furniture, containers and construction, while red oak and hard maple were important species for furniture, flooring, railroad ties, and pallets. Less than one percent of the region's saw log production is exported, although some saw log shipments occur among the region's states. Michigan is the region's largest saw log producer with Wisconsin a close second. Wisconsin, however, exhibits the greatest volumes delivered to mills in the region. This is explained by saw log imports from Michigan's western upper peninsula as well as a smaller number of imports from Minnesota. Saw log imports to the Lake States, like exports, are insignificant.

Future Consumption

Since World War II, more efficient manufacture and use of lumber and the substitution of plywood and particleboard panels for various lumber products have resulted in a decline in lumber-use by end-product within the Lake States region. Residential construction, traditionally the largest end-use for lumber, has, for example, been affected by three key developments (Spelter and Phelps 1984):

- More efficient utilization of lumber framing;
- Substitution of plywood for boards in sheathing;
- Trend toward basementless homes.

Regional growth in residential and industrial end-use markets for lumber will largely determine future lumber consumption by the region. Although the region's growth rate is expected to be lower than the national average, it is still projected at about 7 percent for the 1980-1990 period (Jackson and Masnick 1983; U.S. Department of Commerce, Bureau of Industrial Economics 1983). Such growth would result in substantial increases in lumber consumption within the region.

The Lake States ability to compete with other regions serving national and regional lumber markets will depend heavily on relative stumpage prices. Projections suggest that rising softwood stumpage prices in the U.S., relative to those in Canada, will result in increased imports of Canadian softwood lumber, especially in the Northeast and North Central regions (USDA Forest Service 1982). This scenario is expected to prevail until Canadian timber resources begin to decline in quality and increase in distance from the mills. Given such circumstances, inroads into softwood lumber markets may be difficult for Lake States softwood lumber producers. There is also some question as to whether adequate volumes of softwood saw logs will exist in the region to provide for a competitive softwood lumber industry. Opportunities may exist, however, for Lake States hardwoods to compete in traditional softwood markets. Recent advances in sawing and drying techniques have made feasible the production of construction grade lumber from some lighter hardwood species, such as aspen and yellow poplar (Spelter and Phelps 1984).

As the Lake States forests mature, a growing proportion of the timber will move into the sawtimber size class. Since the majority of this sawtimber will be hardwoods, it appears that the greatest opportunity for the region may be to increase production of hardwood lumber in order to meet the growing requirements in industrial end-use markets. Hardwood lumber production nationwide is projected to increase steadily between 1985 and 1990 by more than 3 percent per year (USDA Forest Service 1982). As long as hardwood stumpage prices in the region do not rise relative to other regions, the Lake States hardwood lumber industry should be able to maintain its market share within regional markets and

thus grow with these markets. Operators of the region's numerous small sawmills, however, will need to stay abreast of the changing technologies and of the product characteristics that lumber-users desire in order to maintain their market share.

PLYWOOD AND VENEER

Veneer logs used in the manufacture of plywood and veneer represent the third most valuable timber product in the Lake States, behind pulpwood and saw logs. Because veneer logs are almost exclusively hardwoods, the region's plywood and veneer industry is essentially a hardwood industry. In addition, more than 90 percent of the veneer logs produced in the region are standard veneer logs (i.e., used in doors, furniture, wall panels, exterior sheathing, and similar items); the remainder is container veneer logs (i.e., used in boxes, crates, packing cases and other containers).

The region's plywood and veneer industry declined between 1950 and 1970, due largely to a decline in Wisconsin's industry (Blyth and Smith 1984b). Since 1970, however, the region's industry has grown, primarily due to growth in Michigan. Future prospects depend upon the industry's ability to compete with other structural panels such as waferboard and oriented strand board in residential and nonresidential construction markets and the industry's adoption of technologies necessary to compete in veneer export markets.

Plywood and Veneer Consumption and Production

Plywood and veneer consumption in the region's major end-use markets totaled 608 million square feet in 1981 (table 3). Residential markets generally represent about half of the region's consumption, with furniture manufacturing constituting the most significant industrial use. Consumption of plywood and veneer in the region is five times greater than regional production. More than 500 million square feet of plywood and veneer is imported into the region each year. These imports consist mostly of softwood plywood from Canada and from western and southern states. Because the hardwood plywood and veneer industry relies more on nonresidential construction markets (e.g., office buildings) than residential markets, production in the Lake States dropped less severely during the 1980 building recession than total plywood and veneer consumption in the region (Stier 1984).

3.--Lake States plywood and veneer consumption by end use

(In million square feet, 3/8-inch basis)

End-use market	1973	1977	1981
Residential			
Single-family	467.2	539.5	201.5
Multi-family	145.0	133.6	59.3
Mobile homes	56.6	28.9	20.9
Alterations and repairs	NA	NA	33.9
Nonresidential buildings	NA	NA	55.5
Industrial			
Pallets	41.9	66.8	85.2
Containers and dunnage	40.8	36.2	34.6
Furniture	89.4	102.4	117.0
Total	840.9	907.4	607.9

Veneer Logs

Veneer log production increased and surpassed receipts in the region during the last two decades. Imports have fallen and exports risen sufficiently to shift the region from a net importer to net exporter. Imports from Canada fell most dramatically (7 million to 0.5 million board feet) although imports from other states (e.g., Iowa, Illinois, and Indiana) showed significant declines as well (5.4 million to 1.6 million board feet). The region's exports are shipped to Indiana, Ohio, and Kentucky and to other countries such as Canada and West Germany.

Twenty-eight plywood and veneer mills were active in the Lake States in 1980. Although the majority were located in Wisconsin, Michigan mills received nearly the same volume—about 27 million board feet (Blyth and Smith 1984b). Wisconsin's plywood and veneer industry gradually declined over the last two decades whereas Michigan's industry showed a sudden growth. A similar but less dramatic pattern occurred for veneer log production in Wisconsin and Michigan. Minnesota's veneer log production declined slightly during this period, although receipts increased substantially in 1980. Both Michigan and Minnesota are net exporters of veneer logs, while Wisconsin is a net importer.

Aspen is the most significant veneer log species in the Lake States, although twenty years ago it was insignificant. Other major veneer log species include hard maple, red oak and yellow birch. Because aspen veneer log production equals consumption, exports from the region are composed of other hardwood species.

Future Consumption and Exports

Although hardwood plywood and veneer products are expected to lose some market share to waferboard and oriented strand board products, growth in construction and industrial markets should be sufficient to generate a net increase in plywood and veneer consumption. Furthermore, waferboard and oriented strand board are expected to compete more with softwood plywood than hardwood plywood and veneer, so domestic markets should show steadier growth for hardwood plywood and veneer than for softwood plywood. Production of hardwood plywood and veneer nationwide is projected to grow at an average rate of nearly 6 percent per year between 1985 and 1990 whereas softwood plywood production is expected to grow at less than 3 percent per year during the same period (USDA Forest Service 1982).

Export markets for plywood and veneer products manufactured in the Lake States show substantial promise, especially European markets (Stier 1984). Although more than one-half of all veneer produced in the U.S. in 1979 was exported, mostly to Europe, Lake States mills have been slow to make the changes necessary to compete in these export markets. In fact most new and efficient veneer mills in the United States are owned by European capitalists (Stier 1984). New capital investment, the adoption of new production techniques and aggressive marketing will probably be needed if the Lake States region is to expand exports to European markets.

Increases in veneer log production and the region's emergence as a net exporter of veneer logs are trends consistent with the maturing of the region's timber resources. The plywood and veneer industry, however, requires high-quality hardwoods; some producers are concerned that although growing-stock trees may be getting larger, quality veneer logs may not be available in the future. The industry also may be troubled by a possible regional reorientation toward fiber production rather than larger timber products.

PARTICLEBOARD

In 1983, the Lake States region secured the position of being the world's leading producer of structural particleboard. Regional production in that year exceeded one billion square feet, a quantity that, for the first time, surpassed Canadian production. Although nationwide production of structural particleboard is expected to increase dramatically over the next 5 to 10 years (especially in the Southeastern United States), Lake States leadership should continue given growth in the region's construction and industrial markets and great opportunity to serve markets in foreign countries (Anderson 1984).

Particleboard is composed of a number of products, each of which adds to confusion over an appropriate definition for "particleboard." For purposes here, particleboard is defined as follows:

- Industrial particleboard—the first of the dry, reconstituted board products introduced, plus medium density fiberboard. These products are generally consumed in industrial uses (e.g., furniture manufacturing).
- Structural particleboard—reconstituted board products (e.g., waferboard, oriented strand board, composite plywood) which generally compete with softwood plywood in construction markets.

Particleboard Consumption and Production

Particleboard consumption within the Lake States probably exceeds 200 million square feet. This estimate assumes that residential construction markets account for about one-half of all particleboard consumption (Pennington 1984). Table 4 does not include estimates of particleboard consumed in several important markets (e.g., residential alterations and repairs, pallets and containers) because national end-use factors, on which to base regional consumption estimates, do not exist.

Particleboard production has grown significantly in the Lake States, especially since 1980. Structural particleboard, for example, grew from approximately 150 million square feet in 1980 to over one billion square feet in 1983. The majority of this growth (70 percent) occurred in Minnesota. The region's capacity to produce industrial particleboard has also increased but at a more moderate rate. In 1982, total regional production of particleboard (structrual and industrial) was nearly one billion square feet and required the use of 675 thousand cords of pulpwood, mostly aspen.

Table 4.--Lake States particleboard consumption by end use

(In million square feet, 3/8-inch basis)

End-Use Market	1973	1977	1981
Residential			
Single-family	49.2	69.8	35.8
Multi-family	9.8	9.8	6.2
Mobile homes	55.4	30.0	19.2
Industrial furniture	20.6	29.6	34.8
Total	135.0	139.2	96.0

Lake States regional exports of particleboard are substantial. In 1983, they probably exceeded 1.3 billion square feet. Large midwestern residential and industrial markets (e.g., Chicago, St. Louis) are very likely the major recipients of these exports. High transportation costs associated with the heavy weight of particleboard may well be curbing the use of Lake States particleboard in more distant markets.

Future Consumption and Exports

The American Plywood Association projects waferboard and oriented strand board production to nearly triple between 1984 and 1990. Two trends supporting this contention are:

- Increases in the average volume of particleboard used per new residential unit; and
- Increased penetration of markets other than residential construction markets (e.g., residential alterations and repairs, nonresidential construction) which grew to 60 percent of total particleboard consumption in 1983 (Pease 1984).

Export markets, particularly in Europe, also represent an opportunity for the structural particleboard industry (Anderson 1984). Future increases in the use of particleboard will depend largely on the industry's ability to maintain low product prices relative to softwood plywood (Spelter 1984).

Major structural-particleboard mill construction programs have been undertaken by U.S. wood-based corporations (e.g., Louisiana-Pacific Corporation and Georgia-Pacific Corporation). Low-cost timber resources seem to be the determining factor in locating mills (Pease 1984). As the industry grows within a region, intensifying competition for timber resources may entail increasing stumpage prices which, in turn, could shift future industry expansion to other regions (Seale and Lyon 1984). In the short run, however, Southern U.S. mills will probably serve rapidly expanding markets in the Sunbelt, while Lake States mills will continue to serve growing Midwestern markets.

The rapid growth of Lake States waferboard and oriented strand board production in the Lake States has raised concern about the adequacy of the region's timber resources, particularly aspen. Concern focuses on meeting the raw material requirements of the particleboard industry as well as the paper and board industry. Hardwoods other than aspen will probably have to satisfy a greater proportion of these future requirements. Oriented strand board production may increase in the region relative to waferboard production since it requires less aspen than the latter (Pennington 1984).

FUELWOOD

Wood was the primary source of energy in the U.S. during the late 1800's and remained a major source of residential heat until the 1930's. As fossil fuels became popular, wood used for fuel declined until the 1970's when fossil fuel prices began to rise. Between 1974 and 1981, the use of wood fuels in the U.S. rose by 45 percent, due to increases in both residential and industrial use (Blyth *et al.* 1984).

Fuelwood Consumption

Residential consumption of fuelwood in the Lake States in 1980 was about 4.4 million cords. Only about one-fifth of the urban households (i.e., those located in villages and cities of 2,500 people or more) used wood for fuel, compared to nearly one-half of the rural households. Also, urban households, on average, burned only 1.6 cords in that year whereas rural households burned 3.1 cords (Skog and Watterson 1984). Since then, residential fuelwood consumption has grown significantly, as indicated by 45 and 75 percent increases in Michigan and Wisconsin, respectively, between 1980 and 1981. A slowing trend, however, may be seen between 1981 and 1982 in Michigan where residential fuelwood consumption increased by only 10 percent. This was probably due to a declining rate in the number of homes converting to fuelwood as a major heating source.

Industrial use of fuelwood in the region is also increasing and should continue to rise as the relative costs of alternative fuels rise. In 1981, about 40 percent of all primary wood-using mill residues produced in Wisconsin, or about 250 thousand tons of residue, were consumed as fuel. About three-fifths were used by industrial consumers while the remainder went to residential consumers. Since all primary wood-using mill residues in Wisconsin are currently being consumed, as fuel or in other wood product manufacturing, increased industrial use of fuelwood will result either directly or indirectly in expanded use of logging residue, such as tops and limbs, imports of residues, or increased roundwood harvesting (Blyth *et al.* 1984).

Michigan and Minnesota both consume considerably less primary wood-using mill residue than they generate (Michigan DNR 1979; Minnesota DNR 1983). Thus, sufficient residue is available for increased industrial fuelwood use in the near future.

Indeed, Minnesota forestry officials consider excess primary wood-using mill residue plus the State's considerable logging residue a significant resource for energy purposes (Minnesota DNR 1983).

Fuelwood Production

The region's only intensive survey of fuelwood production was completed in 1981 in Wisconsin (Blyth *et al.* 1984). Nearly 90 percent of the fuelwood consumed in the State was produced from roundwood. Households dominated this production, producing 7 out of every 8 cords. In the more heavily forested areas of the north, however, loggers harvested 1 out of every 4 cords. Private rural woodland was the major source of fuelwood in Wisconsin, providing more than 90 percent of the State's overall production. However, in the northern portions of the State public lands provided about one-fourth of the fuelwood harvest. Nongrowing stock on commercial forest land (e.g., dead trees, cull trees, tops and limbs) provided more than 60 percent of the fuelwood harvest. Growing-stock accounted for only 15 percent overall, although it represented between 20 and 24 percent of production in the States northern area. Hardwoods represented 96 percent of Wisconsin's fuelwood harvest. Red oak and elm were the dominant species; hard maple, white oak, aspen, white birch, and ash were also significant contributors.

Future Consumption and Exports

Future growth or decline in residential fuelwood consumption in the Lake States will depend largely on the price of wood fuels relative to alternative fuels. Rural households will probably use notably more fuelwood if prices of alternative fuels rise; urban households, however, may not increase fuelwood use as significantly since they face higher dollar costs and greater inconveniences in using wood fuels (Skog and Watterson 1984). Industrial consumption is expected to increase also, as the relative price and environmental advantages of fuelwood become more pronounced. Primary wood-using residue and logging residue will probably provide for some of this increased consumption over the short run; in the long run, however, an increasing proportion will probably come from roundwood. More efficient logging and sawing techniques will probably result in lower rates of residue production, and competition for residue between fuelwood and other products will probably increase.

In 1981 about 15 percent of all roundwood harvested in Wisconsin came from growing stock on commercial forest land. In volume, this represented enough roundwood to supply one 500 ton-per-day pulpmill for one year (Blyth *et al.* 1984). Assuming that this 15 percent ratio applied to each of the Lake States, growing stock harvested for fuelwood in the region represented the annual requirements of more than three 500 ton-per-day pulpmills. Currently, this volume is relatively insignificant. As fuelwood consumption increases, however, it may infringe upon the growing pulpwood requirements of the paper and board and particleboard industries. This may result in upward price pressures for hardwoods in the North Central Region (USDA Forest Service 1984).

SUMMARY AND CONCLUSIONS

The Lake States forest represents an important economic resource which holds promise for relieving some of the region's economic woes. Forest resource managers and planners are searching for appropriate strategies to encourage growth in the region's wood products economy while also ensuring long-term timber supply.

Timber Resources

Forty-five million acres of commercial forest land comprise the Lake States forest. Nearly half is publicly owned, with state and county ownership accounting for about 26 percent. This high proportion of non-federal public ownership represents an opportunity, unique to the Lake States, for state and local governments to have a major influence on the future of the region's forest.

Aspen-birch is the dominant forest type in the region (32 percent coverage of the commercial forest land) with maple-beech-birch and spruce-fir types following in importance (24 percent and 15 percent coverage, respectively). Oak-hickory, white-red-jack pine and elm-ash-cottonwood types account for the remainder.

The Lake States is the nation's only region in which pole-size timber predominates, covering 45 percent of the commercial forest land. The preponderance of 40 to 60 year old aspen and birch partially explains this unique characteristic. It also accounts for the skewed age-class distribution evident in the region. This "wall of wood" phenomenon raises important questions about the utilization of the exist-

ng timber resource and the achievement of the orest's productive capability.

Hardwoods account for three-quarters of the re-ion's growing-stock volume. Despite an eight per-ent decline in commercial forest land over the last wo decades, growing-stock volumes of hardwoods nd softwoods have increased substantially. For nost species, growth has exceeded removals by a ignificant margin. The productive-potential of the ake States forest is low relative to other regions; owever, the region has a greater opportunity than nany others to improve upon its current productiv-ty.

Prospects for the development of the Lake States orest are better today than in the past (Shands and Dawson 1984). Advances in technology have effec-ively transformed the region's pole-size hardwoods nto a fiber resource, highly desirable for paper and oard products and for structural particleboard prod-cts such as waferboard and oriented strand board.

Paper and Board

In recent years, the region's paper and board in-ustry has increased production of paper relative to oard. As a result, the Lake States has become one f the largest paper-producing regions in the coun-ry, accounting for 16 percent of the nation's total roduction in 1977. The region is a significant net xporter, specializing in the production of fine writ-ng, book and magazine papers. Domestic and inter-ational markets for such products show strong rowth potential and Lake States producers appear o be well-situated to compete in these markets. Iowever, two major issues face the industry: a sig-ificant dependency on imports of woodpulp and oftwood residue and increasing competition for oundwood, primarily aspen.

Lumber

The Lake States lumber industry is characterized y a large number of small sawmills which, in aggre-ate, use about half as much roundwood as the paper nd board industry. Hardwoods, primarily aspen, ed oak, and hard maple, account for three-quarters f the region's production. Hardwood lumber is argely consumed in the manufacture of pallets, con-ainers, and furniture (industrial end-use markets), while softwood lumber is consumed in residential nd nonresidential construction markets. The re-ion's production of hardwood lumber nearly equals egional consumption. Softwood lumber production, however, represents only a small portion of regional consumption. Thus, significant volumes of softwood lumber are imported from Canada and from southern and western states. As long as hardwood stumpage prices in the region do not rise relative to other regions, the hardwood lumber industry should be able to maintain its market share within the region's industrial end-use markets and grow with these markets. Furthermore, recent advances in sawing and drying techniques may create opportunities for hardwood lumber to compete in traditional softwood markets.

Plywood and Veneer

The plywood and veneer industry in the region is essentially a hardwood industry which produces standard veneer logs used in doors, furniture, wall panels, exterior sheathing, and similar items. The industry declined steadily between 1950 and 1970, after which it began to grow. Due to increasing production, the region has become a net exporter of veneer logs. Aspen is the most significant veneer-log species; other species (e.g., hard maple, red oak, and yellow birch) account largely for the region's exports. Hardwood plywood and veneer consumption is relatively insignificant when compared to softwood plywood consumption. Thus, although the region is a net exporter of hardwood plywood and veneer, it imports tremendous volumes of softwood plywood. As a result, total plywood and veneer consumption in the region is five times greater than regional production. Hardwood plywood and veneer is expected to lose some market share to structural particleboard products; however, these relatively new products compete primarily with softwood plywood in residential construction markets. Therefore, markets for hardwood plywood and veneer should show steadier growth than softwood plywood markets. Furthermore, international markets, especially Europe, represent significant opportunities for exports of high-quality hardwood veneer.

Particleboard

The Lake States region is one of the world's leading producers of structural particleboard (e.g., waferboard and oriented strand board). It also produces significant volumes of industrial particleboard. Total particleboard production in the region exceeds regional consumption by more than 1.3 billion square feet. Regional exports probably go to residential and industrial markets in the Midwest. Although structural particleboard production is

expected to increase dramatically in the South, such production will probably serve expanding Southern markets. As long as Lake States producers can maintain competitive prices, they should be able to maintain or increase their share in Midwestern markets. They are also favorably located to compete in export markets, especially in Europe, which are expected to expand once the product gains acceptance. Increasing competition for aspen, the industry's primary roundwood requirement, is a major concern.

Fuelwood

Residential fuelwood consumption in the Lake States was 4.4 million cords in 1980 and has grown significantly since then. Rural households are much more likely than urban households to use wood for fuel and burn nearly twice as much wood per household. Industrial consumption of fuelwood has also been increasing in the region as the relative prices of alternative fuels have risen. Private rural woodland represents the major source of fuelwood in the entire region; however, public forest land contributes about 25 percent in the region's northern portion. Similarly, growing-stock trees provide only about 15 percent of all fuelwood produced in the region, but in the northern portion their share approaches 25 percent. Future growth in residential and industrial fuelwood consumption will depend largely or the price of wood relative to alternative fuel prices. Increasing regional use of wood for fuel may result in upward price pressures for hardwoods.

Policy Implications

Assuming that end-use markets for secondary wood products expand as projected (USDA Forest Service 1982), Lake States regional timber production will probably increase, thereby resulting in greater competition for the region's timber resource. Competition for raw materials appears inevitable between the paper and board industry and the structural particleboard industry: both face strong growth prospects and rely significantly upon aspen. Furthermore, rapid increases in consumption of wood for fuel seem likely to intensify such competition.

A recent study of pulpwood, saw log, and fuelwood consumption in northeastern Minnesota estimated that total timber requirements in 2030 would exceed timber growth, based on current growth levels (Rockel *et al*. 1983). Future requirements for aspen were estimated to exceed aspen growth by a much greater margin. These findings can probably be generalized to the Lake States region; however, a broad array of factors will influence the future of the region's forest and different assumptions can lead to markedly different results (Adams and Haynes 1985). Among factors important to the region's forestry sector, other than traditional ones of population growth, general levels of economic activity and forest management intensity, are:

- Expansion of export trade;
- Increased use of low-quality hardwoods other than aspen in the product-species mix;
- Growing consumption of wood for energy;
- Improvements in wood utilization, both in logging and manufacturing; and
- Shifting stumpage prices in other regions of the United States and Canada with respect to those in the Lake States.

Forest resource managers and planners may have difficulty anticipating the effects of these factors, especially in the distant future. They can, however, assess the region's strengths and weaknesses, many of which have been identified here, and subsequently, take steps that will enable the region to capitalize upon opportunities as well as minimize the effects of threats.

Increased cooperation among the three states appears to hold significant potential benefits for the region. Coordination of certain forest policies and programs, for example, could enhance wood products trade between the states, resulting in improved utilization of the region's timber resource and a reduced dependency on imports. Improved systems of information exchange and the revision or elimination of laws and regulations which impede wood products trade represent initial steps toward achieving such objectives.

A positive regional forestry image also may benefit the region's wood producing and manufacturing sector. It could serve as the basis of both a campaign to promote the region's forestry opportunities among policy-makers at the national and regional levels and a marketing strategy to attract new wood products industry investment to the Lake States rather than other regions. Cooperation is the key to successfully developing such a regional image.

Research and Information Needs

The process of systematically gathering and organizing information about the production and consumption of major wood products in the Lake States

emonstrates our limited knowledge of the region's ood products trade. Further research is needed in a umber of areas to reduce the uncertainty and im- ove our understanding. Three areas appear to war- nt the greatest attention:

Wood product flows and market structure. Without better information about the markets to which Lake States wood products flow and reasons for the development of such trade patterns, it is extremely difficult to assess opportunities and design strategies for further development of regional wood products industries. A well-designed survey of regional wood products producers, wholesalers and retailers could obtain such information. Current directories of primary and secondary wood-using mills are available for each state to assist in such a survey (Michigan DNR 1985; Milton and Krantz 1982; Wisconsin DNR 1982a, 1982b). Also, utilization and marketing specialists in each state could probably provide valuable information.

Regional wood product prices. Wood product prices in Midwestern markets hold important implications about the competitive position of Lake States wood products industries with respect to such industries in other regions. A study of comparative prices for wood products from competing regions (e.g., the Lake States, the South, Canada) could provide useful information to assess the potential for expanding the market share of Lake States industries in major Midwestern wood products markets.

Regional forest policies. A systematic identification of regional forest policies (local, state, federal) which affect investment and trade by wood products industries is needed to assess opportunities for improving the environment for such activities. A comparison of Lake States policies with those in other regions could be useful for determining the region's policy strengths and weaknesses.

During the course of this review, the statistical idence on wood product production and consumption often proved to be lacking, outdated or inconsistent between states. Some of the more critical information needs are as follows:

Timber inventory data by state for comparable periods of time.

State or regional consumption, import and export data for paper and board products.

State or regional import and export data for woodpulp.

Separate reports for pulpwood used in particleboard production as opposed to paper and board production.

- More regular and reliable reporting of lumber production by state.
- Saw log production, import and export data by state for comparable years.
- Hardwood plywood and veneer production, import and export data for the region.
- Consistent particleboard product definitions.
- State or regional production, consumption, import and export data for defined particleboard products.
- Residential and industrial fuelwood production and consumption data by state.
- Regional use-factors for major wood products in major end-use markets
- Single- and multi-family housing starts by state.
- Mobile home production by state.
- Expenditures on residential alterations and repairs by state.
- State or regional pallet production.
- State or regional furniture production indexes.

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GLOSSARY

Commercial forest land.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization.

Composite plywood (COM-PLY).—A structural panel that combines a reconstituted board core with a veneer cover top and bottom.

Demand indicator.—(See Use-factor approach.)

Diameter classes.—A classification of trees based on diameter outside bark, measured at breast height (4.5 feet above the ground).

End-use market.—(See Use-factor approach.)

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use.

Forest site productivity class.—A classification of forest land in terms of potential cubic-foot volume

growth per acre at culmination of mean annual increment in fully stocked natural stands.

Forest type.—A classification of forest land based upon the tree species forming a plurality of the stocking.

White-red-jack pine.—Forests in which eastern white, red pine, or jack pine, singly or in combination, comprise a plurality of the stocking.

Spruce-fir.—Forests in which spruce or true firs, singly or in combination, comprise a plurality of the stocking.

Oak-hickory.—Forests in which upland oaks, or hickory, singly or in combination, comprise a plurality of the stocking.

Elm-ash-cottonwood.—Forests in which elm, ash, or cottonwood, singly or in combination, comprise a plurality of the stocking.

Maple-beech-birch.—Forests in which maple, beech, or yellow birch, singly or in combination, comprise a plurality of the stocking.

Aspen-birch.—Forests in which aspen, balsam poplar, paper birch, or gray birch, singly or in combination, comprise a plurality of the stocking.

Growing-stock trees.—Live sawtimber trees, poletimber trees, saplings, and seedlings meeting specified standards of quality or vigor; excludes cull trees.

Growing-stock volume.—Net volume in cubic feet of live sawtimber and poletimber trees from stump to a minimum 4-inch top (of central stem) outside bark or to the point where central stem breaks into limbs.

Growth.—(See Net annual growth.)

Hard pine.—Includes red pine and jack pine.

Logging residue.—The unused portions of poletimber and sawtimber trees cut or killed by logging.

Medium-density fiberboard (MDF).—Combines technologies of hardboard and early industrial particleboard to create new panel product for furniture manufacturers.

Net annual growth.—The net increase in the volume of trees during a specified year. Components of net annual growth include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year, and minus the net volume of trees that became rough or rotten during the year.

Nonforest land.—Land that has never supported forests and land formerly forested where use of timber management is precluded by development for other uses.

Nonstocked areas.—Commercial forest land less than 10 percent stocked with growing-stock trees.

Other hardwoods.—Includes all hardwoods other than aspen.

Other softwoods.—Includes all softwoods other than hard pine, i.e., red pine and jack pine.

Oriented strand board (OSB).—A reconstituted board product which attempts to duplicate the physical properties of plywood through orientation of the wood particles or strands.

Particleboard.—Reconstituted board products manufactured by reducing solid wood to smaller components (i.e., particles, fibers, strands, flakes, wafers, etc.) and then gluing the small components back together again into a usable board product.

Structural particleboard.—Generally includes waferboard, OSB, and composite plywood or comply. These products compete primarily with softwood plywood in construction markets.

Industrial particleboard.—Generally includes "particleboard" (i.e., the first of the dry, reconstituted board products introduced) and medium-density fiberboard. (Hardboard is sometimes included as well; in this study, however, it is contained within paper and board.) These products are consumed in industrial uses, primarily furniture manufacturing.

Poletimber.—(See Stand-size class.)

Primary timber product.—Roundwood products, such as pulpwood, saw logs, veneer logs, and fuelwood. Mill residues are also included if they reenter the primary-mill processing stage.

Primary timber product production.—The annual quantity, determined from mill receipts of one or a group of roundwood products cut in a specific geographic area, plus the annual wood residue quantity produced by sawmills, veneer mills, etc., in a specific geographic area that was used for the product.

Primary timber product receipts.—The annual quantity of wood received by mills in a specific geographic area, regardless of the geographic source.

Primary wood-using mill.—Mills receiving roundwood or chips from roundwood.

Primary wood-using mill residue.—Wood materials and bark not utilized for principal products at primary mills using roundwood.

Removals.—The net volume of growing-stock or sawtimber trees removed from inventory by harvesting; cultural operations, such as timber stand improvement; land clearings; or changes in land use.

Roundwood.—Logs, bolts, or other round sections cut from trees.

Sawtimber.—(See Stand-size class.)

Secondary timber product.—Primary timber products which undergo further processing, such as paper and board, lumber, plywood and veneer, and particleboard.

Site class.—(See Forest site productivity class.)

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-size class.—A classification of forest land based on the size class of growing-stock trees on the area; that is, sawtimber, poletimber, or seedlings and saplings.

Sawtimber.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, International 1/4-inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Poletimber.—Growing-stock trees of commercial species at least 5 inches in diameter at breast height, but smaller than sawtimber size.

Saplings.—Live trees 1 to 5 inches in diameter at breast height.

Structural panel.—Includes softwood plywood as well as reconstituted board products which compete with plywood, such as waferboard, OSB, and composite plywood.

Use-factor approach.—Method of estimating product consumption (e.g., secondary wood product consumption) in major end-use markets which employs use-factors and demand indicators.

Demand indicator.—An indicator of the level of activity in an end-use market.

End-use market.—Major markets or activities in which products (e.g., secondary wood products) are used or consumed.

Use-factor.—A measure of product consumed (e.g., wood consumed) per unit of activity in an end-use market.

APPENDIX

HOW TO USE THE APPENDIX

Figures and tables in the appendix are organized in groups that correspond to the major timber resource and product sections in the text. These groups are shown below in conjunction with appropriate text section titles:

Figures	Tables	Title
2 - 8	5 - 13	Regional timber resources
9 - 28	14 - 29	Paper and board
29 - 35	30 - 47	Lumber
36 - 47	48 - 65	Plywood and veneer
48 - 50	66 - 71	Particleboard
	72	Fuelwood

Within the timber product sections, specific product categories are broken out (e.g., lumber used in pallet production, plywood used in residential alterations and repairs). Data for the individual States are given, usually along with Lake States totals. In order to find how much lumber was used, say, in furniture manufacturing in Minnesota, one would look to the group of Lumber tables (i.e., tables 30 - 47), locate the product category for lumber used in furniture manufacturing (i.e., table 39), and read the data for Minnesota.

FIGURE CAPTIONS

Figure 1.—*Primary and secondary wood product flows in the Lake States*.

Figure 2.—*Commercial forest land ownership in the Lake States*.

Figure 3.—*Forest types in the Lake States*.

Figure 4.—*Site classes in the Lake States*.

Figure 5.—*Stand-age classes in the Lake States*.

Figure 6.—*Lake States growing stock by diameter class*.

Figure 7.—*Lake States growing stock by ownership and species group*.

Figure 8.—*Lake States growing stock by species group and state*.

Figure 9.—*Lake States paper and board production and consumption*.

Figure 10.—*Paper production and board production in the Lake States*.

Figure 11.—*Paper and board production in the Lake States*.

Figure 12.—*Paper and board consumption in the Lake States*.

Figure 13.—*Lake States woodpulp production and consumption*.

Figure 14.—*Woodpulp production in the Lake States*.

Figure 15.—*Woodpulp consumption in the Lake States*.

Figure 16.—*Pulpwood production and receipts in the Lake States.*
Figure 17.—*Pulpwood production in the Lake States.*
Figure 18.—*Pulpwood receipts in the Lake States.*
Figure 19.—*Roundwood pulpwood production and receipts in the Lake States.*
Figure 20.—*Production and receipts of pulpwood residues in the Lake States.*
Figure 21.—*Roundwood pulpwood production in the Lake States by species groups.*
Figure 22.—*Roundwood pulpwood receipts in the Lake States by species groups.*
Figure 23.—*Production and receipts of hard pine roundwood pulpwood in the Lake States.*
Figure 24.—*Production and receipts of other softwood roundwood pulpwood in the Lake States.*
Figure 25.—*Production and receipts of aspen roundwood pulpwood in the Lake States.*
Figure 26.—*Production and receipts of other hardwood roundwood pulpwood in the Lake States.*
Figure 27.—*Lake States pulpwood imports and exports.*
Figure 28.—*Pulpwood imports to the Lake States from other states and Canada.*
Figure 29.—*Hardwood lumber production and consumption in the Lake States.*
Figure 30.—*Softwood lumber production and consumption in the Lake States.*
Figure 31.—*Hardwood lumber consumption in the Lake States by end use.*
Figure 32.—*Softwood lumber consumption in the Lake States by end use.*
Figure 33.—*Saw log production and receipts in Michigan.*
Figure 34.—*Saw log production and receipts in Wisconsin.*
Figure 35.—*Saw log production and receipts in Minnesota.*
Figure 36.—*Hardwood veneer log receipts in the Lake States.*
Figure 37.—*Plywood and veneer consumption in the Lake States.*
Figure 38.—*Lake States plywood and veneer consumption by end use.*
Figure 39.—*Veneer log production and receipts in the Lake States.*
Figure 40.—*Veneer log production in the Lake States.*
Figure 41.—*Veneer log receipts in the Lake States.*
Figure 42.—*Veneer log production in the Lake States by species groups.*
Figure 43.—*Veneer log receipts in the Lake States by species groups.*
Figure 44.—*Lake States veneer log imports and exports.*
Figure 45.—*Veneer log imports to the Lake States from other states and Canada.*
Figure 46.—*Production and receipts of aspen veneer logs in the Lake States.*
Figure 47.—*Production and receipts of other hardwood veneer logs in the Lake States.*
Figure 48.—*Structural panel production in the Lake States.*
Figure 49.—*Particleboard productive-capacity in the Lake States.*
Figure 50.—*Lake States particleboard consumption by end use.*

TABLE TITLES

Table 1.—Lumber market definitions
Table 2.—Lake States lumber consumption by end use
Table 3.—Lake States plywood and veneer consumption by end use
Table 4.—Lake States particleboard consumption by end use
Table 5.—Forest land area in the Lake States by land class
Table 6.—Commercial forest land ownership in the Lake States
Table 7.—Lake States forest types on commercial forest land
Table 8.—Lake States commercial forest land area by stand-age class
Table 9.—Lake States commercial forest land area by site class
Table 10.—Net volume of growing-stock in the Lake States by ownership and species group
Table 11.—Net volume of growing-stock in the Lake States by forest type
Table 12.—Net volume of growing-stock in the Lake States by species group
Table 13.—Net volume of growing-stock in the Lake States by diameter class
Table 14.—Paper and board production and consumption in the Lake States
Table 15.—Woodpulp production and consumption in the Lake States
Table 16.—Wastepaper utilization by paper and board mills in the Lake States
Table 17.—Paper and board production and consumption in Michigan, Wisconsin, and Minnesota
Table 18.—Woodpulp production and consumption in Michigan, Wisconsin, and Minnesota
Table 19.—Wastepaper utilization by paper and board mills in Michigan, Wisconsin, and Minnesota

Table 20.—Pulpwood production in the Lake States
Table 21.—Pulpwood receipts in the Lake States
Table 22.—Lake States pulpwood imports and exports
Table 23.—Lake States pulpwood production for flakeboard plants
Table 24.—Pulpwood production in Michigan, Wisconsin, and Minnesota by state of destination.
Table 25.—Pulpwood production in the Lake States, Michigan, Wisconsin, and Minnesota by species group
Table 26.—Pulpwood receipts in Michigan, Wisconsin, and Minnesota by state of origin
Table 27.—Pulpwood receipts in the Lake States, Michigan, Wisconsin, and Minnesota by species group
Table 28.—Pulpwood imports into Michigan, Wisconsin, and Minnesota by species group
Table 29.—Pulpwood exports from Michigan, Wisconsin, and Minnesota by species group
Table 30.—Lumber production in the Lake States, Michigan, and Wisconsin
Table 31.—Lumber production in Minnesota and West North Central division
Table 32.—Residential construction in Michigan, Wisconsin, and Minnesota
Table 33.—Lumber used in single-family home construction in Michigan, Wisconsin, Minnesota, and the Lake States
Table 34.—Lumber used in multi-family home construction in Michigan, Wisconsin, Minnesota, and the Lake States
Table 35.—Lumber used in new mobile homes in Michigan, Wisconsin, Minnesota, and the Lake States
Table 36.—Lumber used in residential alterations and repairs in Michigan, Wisconsin, Minnesota, and the Lake States
Table 37.—Lumber used in nonresidential building construction in Michigan, Wisconsin, Minnesota, and the Lake States
Table 38.—Lumber used in pallet manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States
Table 39.—Lumber used in container and dunnage manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States
Table 40.—Lumber used in furniture manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States
Table 41.—Lumber used in other manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States
Table 42.—Saw log production in Michigan, Wisconsin, and Minnesota by state of destination
Table 43.—Saw log production in Michigan, Wisconsin, and Minnesota by species group
Table 44.—Saw log receipts in Michigan, Wisconsin, and Minnesota by state of origin
Table 45.—Saw log receipts in Michigan, Wisconsin, and Minnesota by species group
Table 46.—Saw log imports into Michigan, Wisconsin, and Minnesota by species group
Table 47.—Saw log exports from Michigan, Wisconsin, and Minnesota by species group
Table 48.—Hardwood veneer log receipts in the Lake States
Table 49.—Plywood used in single-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota
Table 50.—Plywood used in multi-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota
Table 51.—Plywood used in new mobile homes in the Lake States, Michigan, Wisconsin, and Minnesota
Table 52.—Plywood used in residential alterations and repairs in the Lake States, Michigan, Wisconsin, and Minnesota
Table 53.—Plywood used in nonresidential building construction in the Lake States, Michigan, Wisconsin, and Minnesota
Table 54.—Plywood and veneer used in furniture manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota
Table 55.—Plywood and veneer used in pallet manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota
Table 56.—Plywood and veneer used in container and dunnage manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota
Table 57.—Veneer log production in the Lake States
Table 58.—Veneer log receipts in the Lake States
Table 59.—Veneer log imports and exports in the Lake States
Table 60.—Veneer log production in Michigan, Wisconsin, and Minnesota by state of destination
Table 61.—Veneer log production in the Lake States, Michigan, Wisconsin, and Minnesota by species group
Table 62.—Veneer log receipts in Michigan, Wisconsin, and Minnesota by state of origin
Table 63.—Veneer log receipts in the Lake States, Michigan, Wisconsin, and Minnesota by species group
Table 64.—Veneer log imports into Michigan, Wisconsin, and Minnesota by species group
Table 65.—Veneer log exports from Michigan, Wisconsin, and Minnesota by species group

Table 66.—Structural panel production in the Lake States
Table 67.—Particleboard productive-capacity in the Lake States
Table 68.—Particleboard used in single-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota
Table 69.—Particleboard used in multi-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota
Table 70.—Particleboard used in new mobile homes in the Lake States, Michigan, Wisconsin, and Minnesota
Table 71.—Particleboard used in furniture manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota
Table 72.—Residential fuelwood consumption in the Lake States

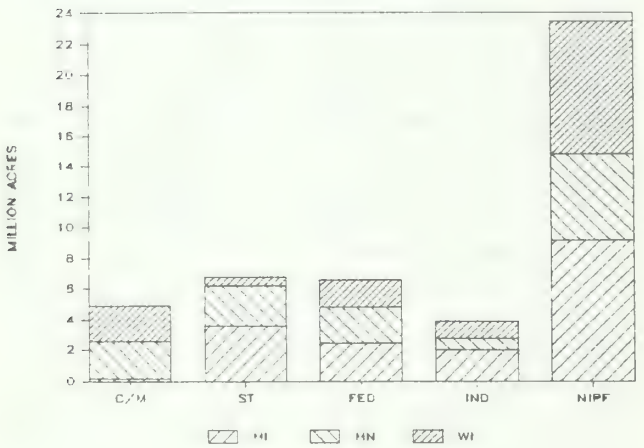


Figure 2.—*Commercial forest land ownership in the Lake States.*

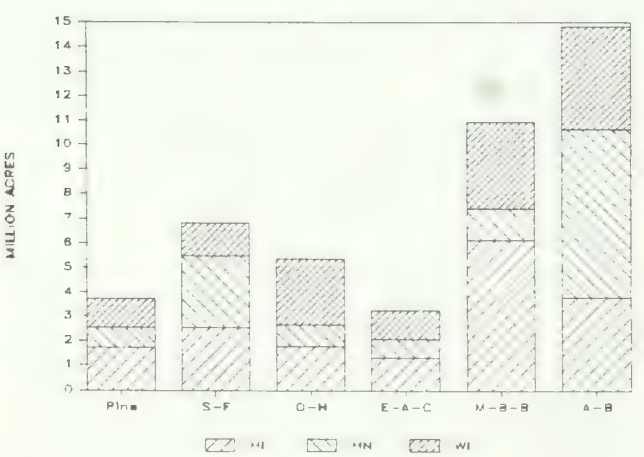


Figure 3.—*Forest types in the Lake States.*

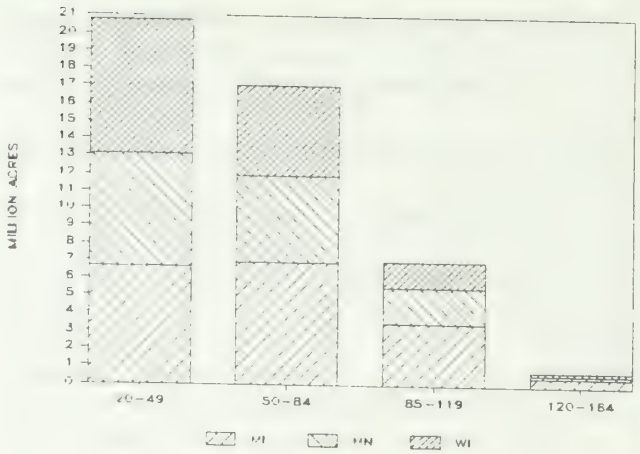


Figure 4.—*Site classes in the Lake States.*

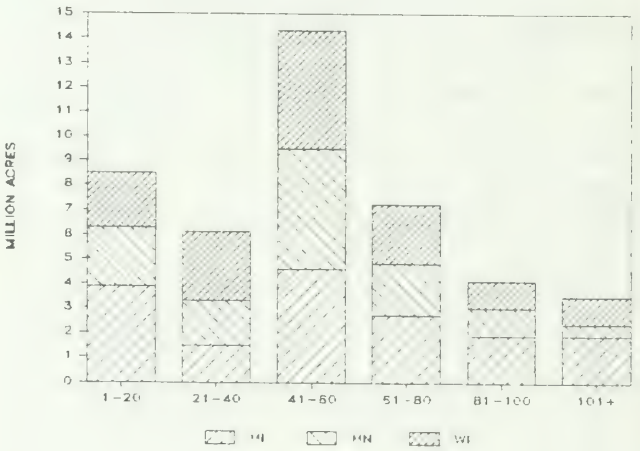


Figure 5.—*Stand-age classes in the Lake States.*

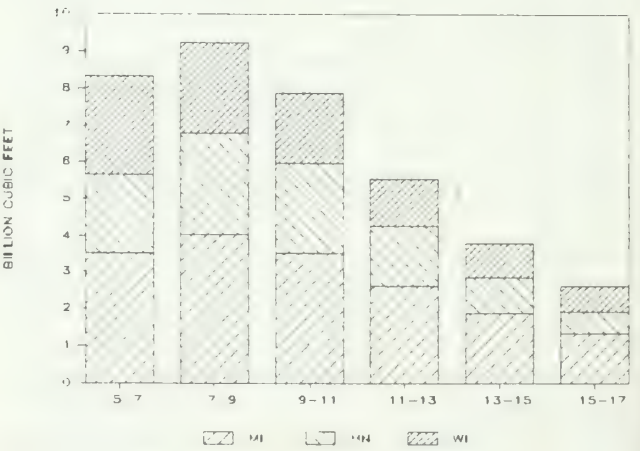


Figure 6.—*Lake States growing stock by diameter class.*

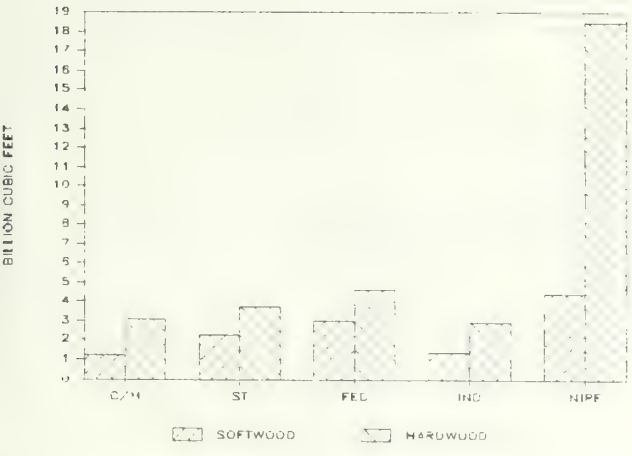


Figure 7.—*Lake States growing stock by ownership and species group.*

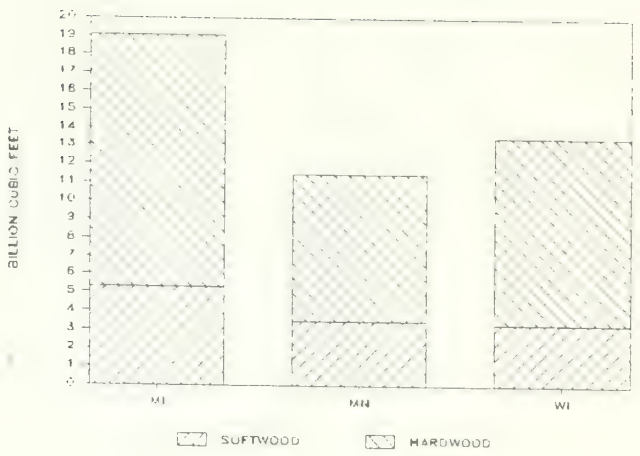


Figure 8.—*Lake States growing stock by species group and state.*

Table 5.--Forest land area in the Lake States by land class

(In million acres)

Forest land class	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
Commercial	17.5	13.7	14.5	45.7
Noncommercial				
Unproductive	.3	1.8	.4	2.5
Productive-reserved	.6	1.2	.0	1.8
Total	18.4	16.7	14.9	50.0

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ USDA Forest Service (1982).

Table 6.--Commercial forest land ownership in the Lake States

(In million acres)

Ownership	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
County/municipal	0.2	2.3	2.4	4.9
State	3.6	2.7	.6	6.8
Federal	2.5	2.3	1.8	6.6
Industry	2.0	0.8	1.2	3.9
Farm/nonindustrial private	9.2	5.6	8.6	23.5
Total	17.5	13.7	14.5	45.6

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ USDA Forest Service (1982).

Table 7.--Lake States forest types on commercial forest land

(In million acres)

Forest type	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
Pine	1.7	0.8	1.2	3.7
Spruce-fir	2.5	2.9	1.3	6.8
Oak-hickory	1.8	.9	2.7	5.3
Elm-ash-cottonwood	1.3	.7	1.2	3.2
Maple-beech-birch	6.1	1.3	3.6	10.9
Aspen-birch	3.8	6.9	4.2	14.8
Nonstocked	.3	.2	.3	.8
Total	17.5	13.7	14.5	45.6

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Raile and Smith (1982).

Table 8.--Lake States commercial forest land area by stand-age class

(In million acres)

Age class	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
1 - 10	2.0	1.2	1.2	4.4
11 - 20	1.9	1.2	1.0	4.1
21 - 30	1.0	1.0	1.3	3.3
31 - 40	1.5	1.8	1.5	4.8
41 - 50	2.3	2.6	2.6	7.5
51 - 60	2.3	2.3	2.2	6.9
61 - 70	1.5	1.3	1.5	4.2
71 - 80	1.2	.8	.9	2.8
81 - 90	1.1	.6	.6	2.2
91 - 100	.8	.5	.5	1.8
101 - 120	1.2	.3	.8	2.3
121 - 140	.5	.2	.3	1.0
141 +	.2	.0[4/]	.0	.2

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Raile and Smith (1982).
4/ Less than 50 thousand cubic feet.

Table 9.--Lake States commercial forest land area by site class

(In million acres)

Site class	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
20 - 49	6.7	6.5	7.7	20.8
50 - 84	6.9	5.0	5.2	17.1
85 - 119	3.5	2.0	1.5	7.0
120 - 164	.5	.2	.2	.8

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Spencer and Thorne (1972).

Table 10.--Net volume of growing-stock in the Lake States by ownership and species group

(In billion cubic feet)

Ownership	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
County/municipal				
Softwood	0.1	0.6	0.6	1.2
Hardwood	.1	1.5	1.5	3.1
State				
Softwood	1.3	.8	.2	2.3
Hardwood	2.2	1.1	.3	3.7
Federal				
Softwood	1.1	1.1	.8	3.0
Hardwood	1.8	1.3	1.5	4.6
Industry				
Softwood	.8	.3	.4	1.4
Hardwood	1.7	.4	.9	2.9
Farm/nonindustrial private				
Softwood	2.1	.8	1.6	4.4
Hardwood	8.0	3.7	6.7	18.5

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Spencer and Thorne (1972).

Table 11.--Net volume of growing-stock in the Lake States by forest type

(In billion cubic feet)

Forest type	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
Pine	1.6	1.0	1.2	3.8
Spruce-fir	2.6	1.8	1.2	5.5
Oak-hickory	2.0	.8	2.1	4.9
Elm-ash-cottonwood	1.3	.6	1.1	2.9
Maple-beech-birch	8.1	1.2	4.3	13.5
Aspen-birch	3.6	5.6	2.9	12.1
Nonstocked	.1	.0[4/]	.0	.1
Total	19.1	11.0	12.7	42.8

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Spencer and Thorne (1972).
4/ Less than 50 thousand cubic feet.

Table 12.--Net volume of growing-stock in the Lake States by species group

(In billion cubic feet)

Species group	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
Softwoods	5.4	3.5	3.3	12.2
Hardwoods	13.8	8.0	10.1	31.9
Total	19.1	11.5	13.5	44.0

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Spencer and Thorne (1972).

Table 13.--Net volume of growing-stock in the Lake States by diameter class

(In billion cubic feet)

Diameter Class	Michigan[1/]	Minnesota[2/]	Wisconsin[3/]	Lake States
5 - 6.9	3.5	2.2	2.7	8.4
7 - 8.9	4.0	2.8	2.5	9.2
9 - 10.9	3.5	2.4	1.9	7.9
11 - 12.9	2.6	1.7	1.3	5.6
13 - 14.9	1.9	1.0	.9	3.8
15 - 16.9	1.3	.6	.7	2.6
17 - 18.9	.9	.4	.5	1.7
19 - 20.9	.5	.2	.3	1.0
21 - 22.9	.3	.1	.2	.6
23 - 28.9	.4	.2	.3	.8
29 +	.1	.1	.1	.2

1/ Raile and Smith (1983).
2/ Jakes (1980b).
3/ Spencer and Thorne (1972).

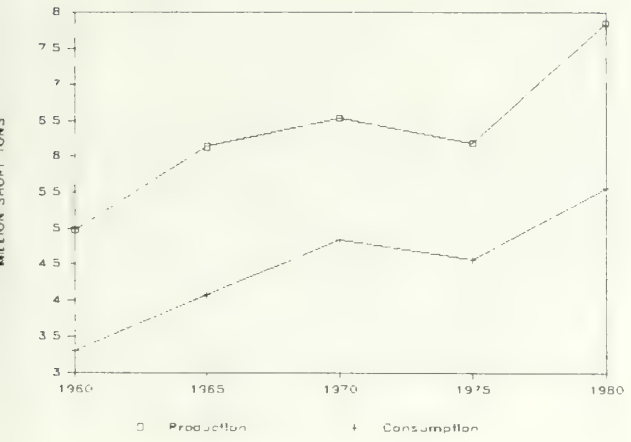


Figure 9.—*Lake States paper and board production and consumption.*

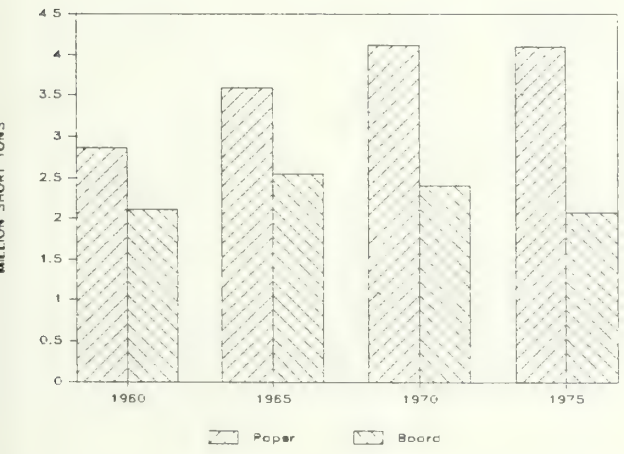


Figure 10.—*Paper production and board production in the Lake States.*

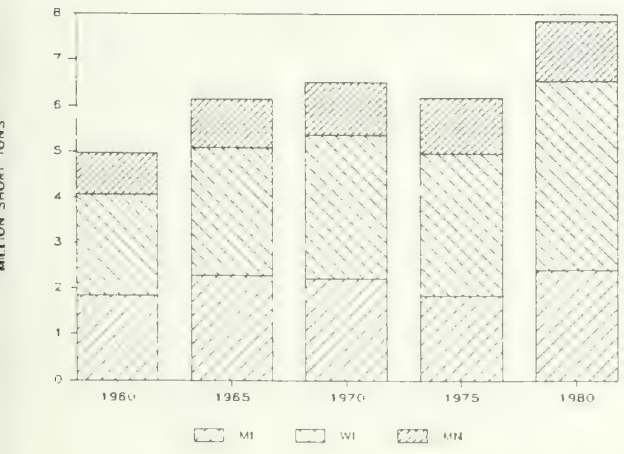


Figure 11.—*Paper and board production in the Lake States.*

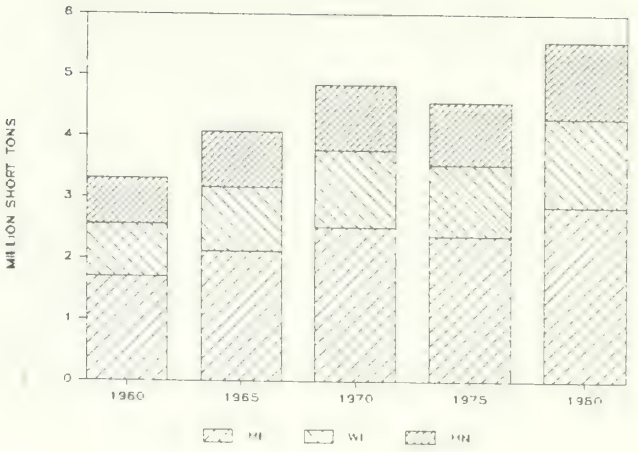


Figure 12.—*Paper and board consumption in the Lake States.*

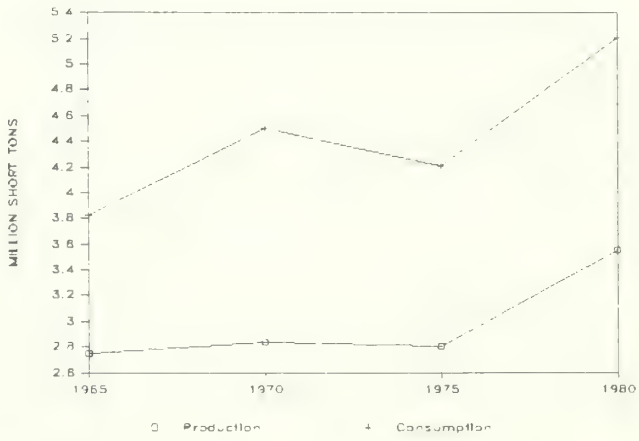


Figure 13.—*Lake States woodpulp production and consumption.*

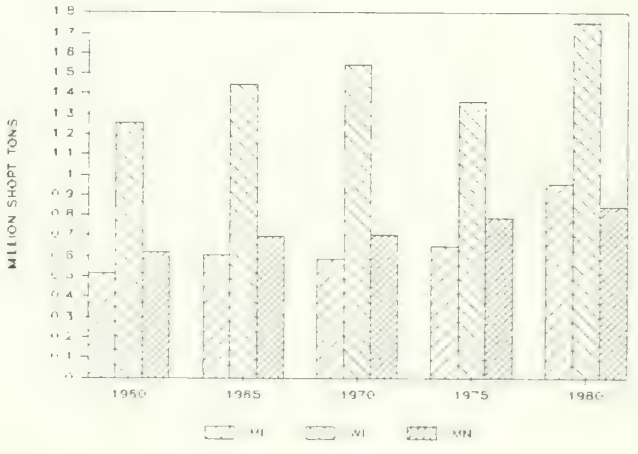


Figure 14.—*Woodpulp production in the Lake States.*

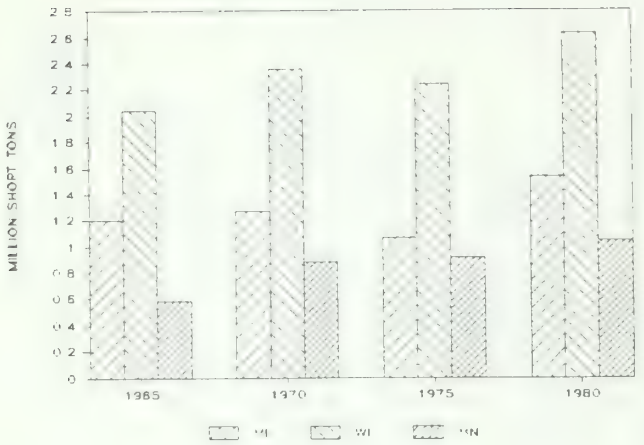


Figure 15.—*Woodpulp consumption in the Lake States.*

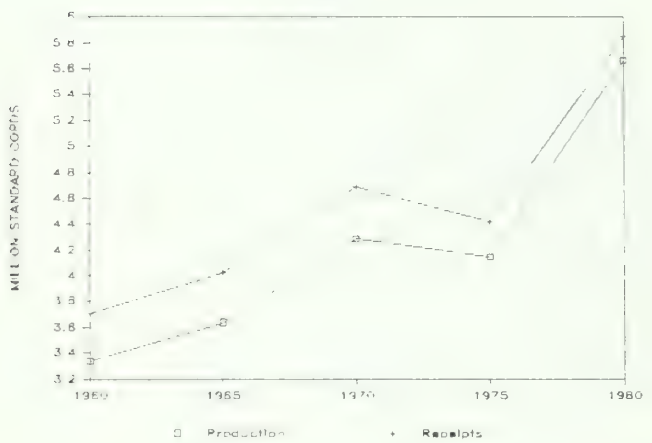


Figure 16.—*Pulpwood production and receipts in the Lake States.*

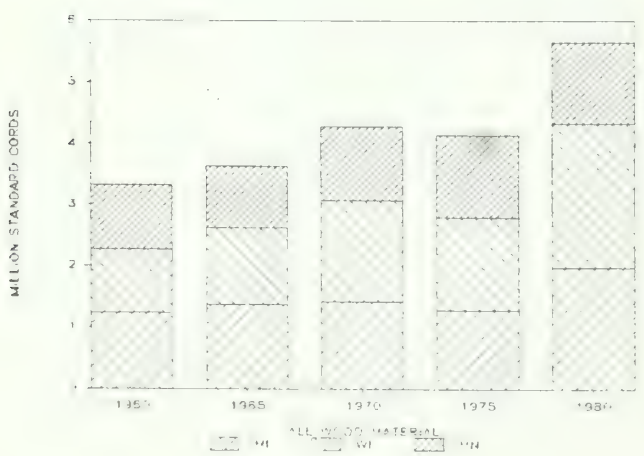


Figure 17.—*Pulpwood production in the Lake States.*

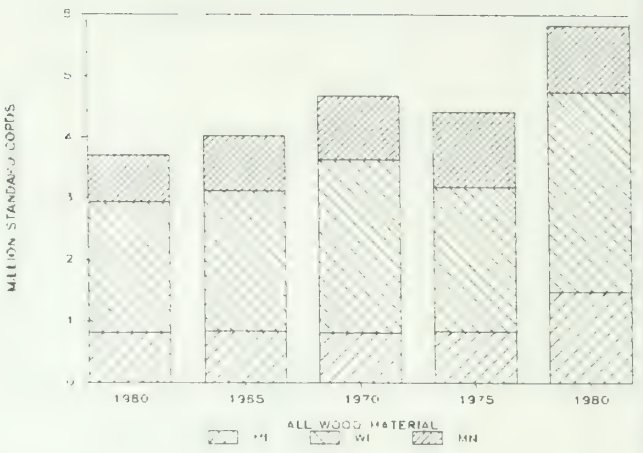


Figure 18.—*Pulpwood receipts in the Lake States.*

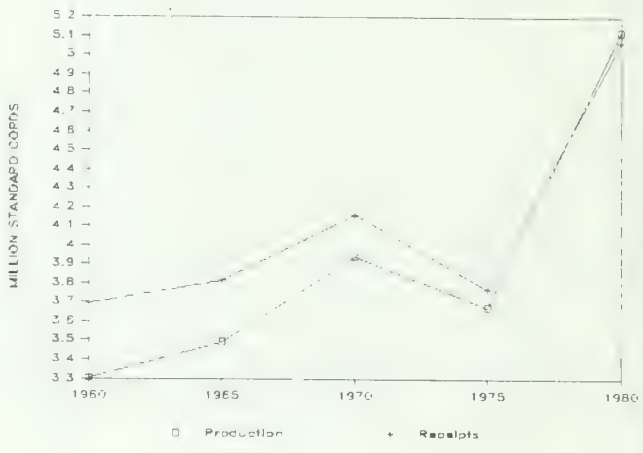


Figure 19.—*Roundwood pulpwood production and receipts in the Lake States.*

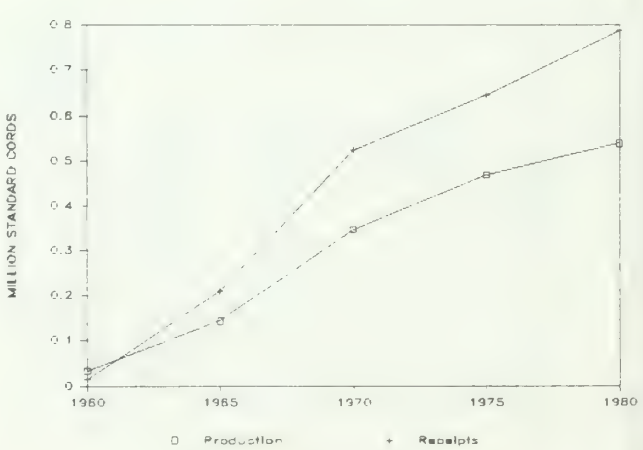


Figure 20.—*Production and receipts of pulpwood residues in the Lake States.*

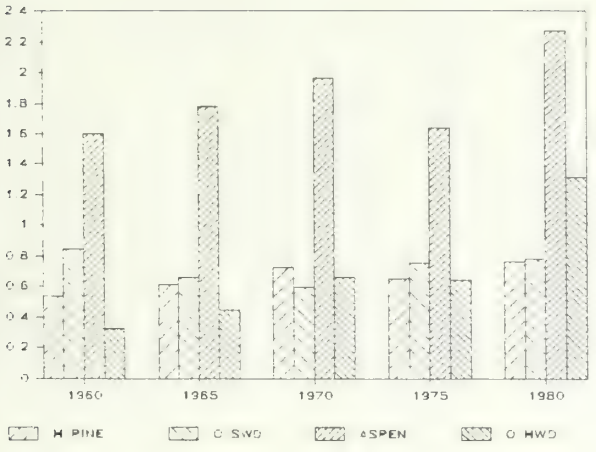


Figure 21.—*Roundwood pulpwood production in the Lake States by species groups.*

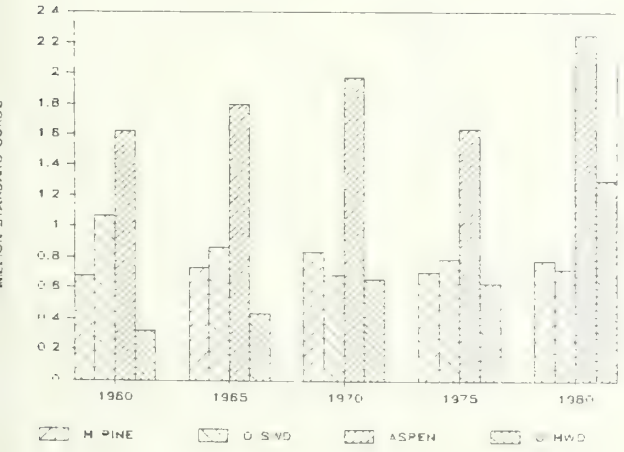


Figure 22.—*Roundwood pulpwood receipts in the Lake States by species groups.*

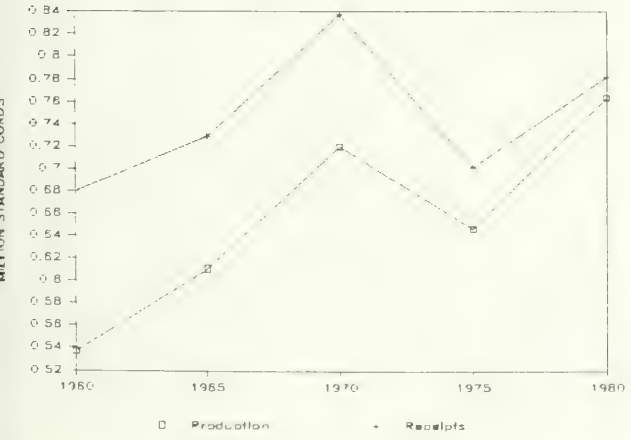


Figure 23.—*Production and receipts of hard pine roundwood pulpwood in the Lake States.*

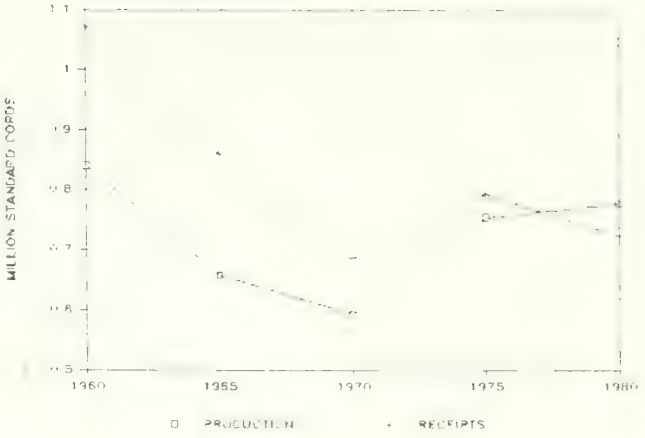


Figure 24.—*Production and receipts of other softwood roundwood pulpwood in the Lake States.*

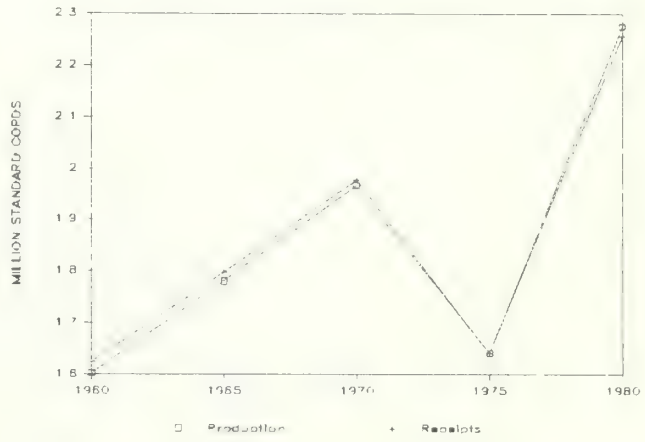


Figure 25.—*Production and receipts of aspen roundwood pulpwood in the Lake States.*

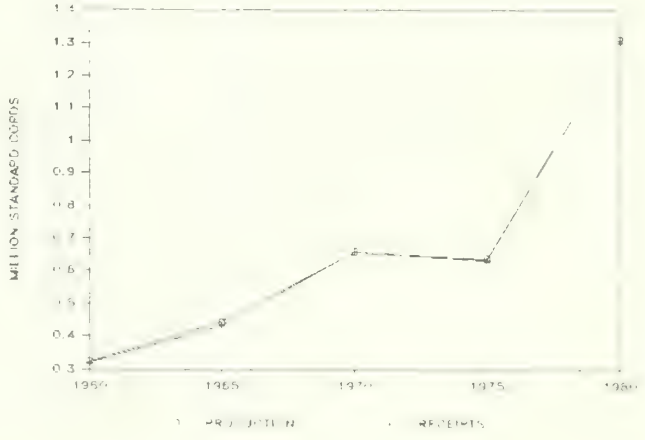


Figure 26.—*Production and receipts of other hardwood roundwood pulpwood in the Lake States.*

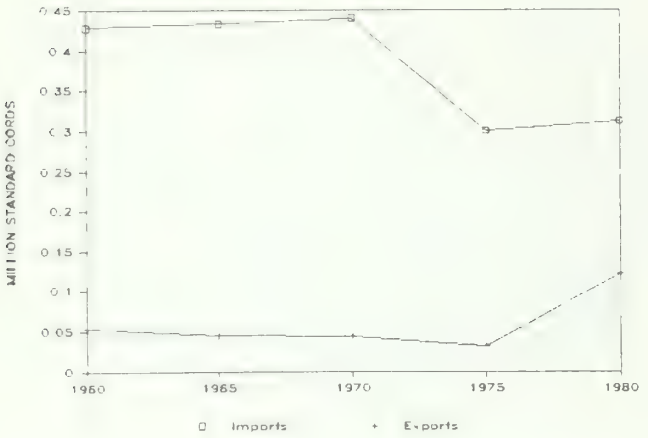


Figure 27.—*Lake States pulpwood imports and exports.*

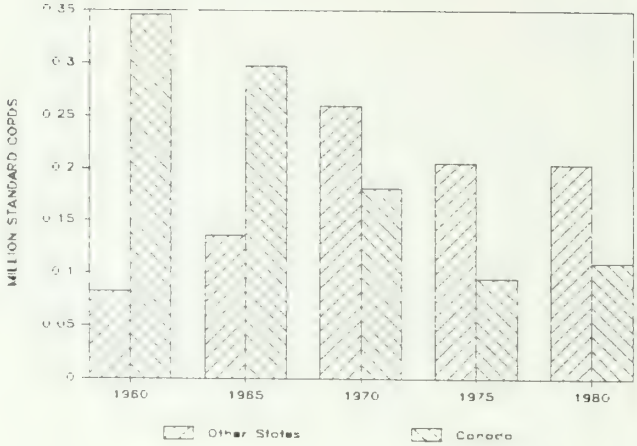


Figure 28.—*Pulpwood imports to the Lake States from other states and Canada.*

Table 14.--Paper and board production and consumption in the Lake States

(In thousand short tons)

Year	Production[1/]	Consumption[2/]
1982		
1981		
1980	7,846	5,564
1979	8,580	5,779
1978	7,793	5,664
1977	7,337	5,432
1976	NA	5,183
1975	6,182	4,559
1974	7,344	
1973	7,563	
1972	7,155	
1971	6,705	
1970	6,527	4,849
1969	6,762	
1968	6,404	
1967	6,118	
1966	6,397	
1965	6,134	
1964	5,770	
1963	5,369	
1962	5,184	
1961	4,931	
1960	4,978	3,296

1/ U.S. Department of Commerce, Bureau of the Census, Current Industrial Report Series M26A.

2/ Based on per capita paper and board consumption (Ulrich 1983).

Table 15.--Woodpulp production and consumption in the Lake States[1/]

(In thousand short tons)

Year	Production	Consumption
1982	3,189[2/]	4,482
1981	3,426	4,911
1980	3,555	5,209
1979	3,593	5,539
1978	3,355	4,983
1977	3,265	4,820
1976	3,201	4,732
1975	2,802	4,207
1974	3,287	5,081[2/]
1973	3,005	5,046[2/]
1972	2,972	4,827[2/]
1971	2,921	4,550[2/]
1970	2,838	4,503[2/]
1969	2,982	4,712[2/]
1968	2,641	4,042[2/]
1967	2,652	4,076[2/]
1966	2,762	3,894[2/]
1965	2,750	3,830[2/]
1964	2,766[2/]	3,762[2/]
1963	2,550	
1962	2,507	
1961	2,421	
1960	2,394	

1/ U.S. Department of Commerce, Bureau of the Census, Current Industrial Report Series M26A.

2/ Minnesota's production and consumption data was not disclosed for these years; therefore, West North Central data represents Minnesota.

Table 16.--Wastepaper utilization by paper and board mills in the Lake States[1/]

(In thousand short tons)

Year	Paper & board produced	Utilization rate[2/]	Wastepaper used
1981	NA	23.9	NA
1980	7,846	23.4	1,836
1979	8,580	23.8	2,042
1978	7,793	23.7	1,847
1977	7,337	23.3	1,710
1976	NA	23.3	NA
1975	6,182	22.9	1,416
1974	7,344	23.6	1,733
1973	7,563	23.5	1,777
1972	7,155	22.5	1,610
1971	6,705	22.8	1,529
1970	6,527	22.8	1,488

1/ American Paper Institute, statistics of paper, paperboard and woodpulp.

2/ The utilization rate equals the ratio of recyclable paper consumption to total production of paper and board.

Table 17.--Paper and board production and consumption in Michigan, Wisconsin, and Minnesota

(In thousand short tons)

Year	Production[1]			Consumption		
	Paper	Board:[2] all grades	Total	Per capita[3]	Residential population	Total
				Pounds	Thousand	
MICHIGAN						
1982	913	[4]	[4]		9,109	
1981	1,177	[4]	[4]		9,215	
1980	1,115	1,289	2,404	616	9,255	2,851
1979	1,290	1,248	2,538	644	9,249	2,978
1978	1,261	1,281	2,542	635	9,202	2,922
1977	1,141	1,300	2,441	612	9,157	2,802
1976	NA	NA	NA	587	9,117	2,676
1975	829	1,026	1,855	518	9,108	2,359
1974	1,133	1,341	2,474	605		
1973	1,134	1,456	2,590	631		
1972	998	1,416	2,414	615		
1971	892	1,383	2,275	575		
1970	955	1,280	2,235	566	8,895	2,517
1969	949	1,356	2,305	582		
1968	910	1,319	2,229	556		
1967	822	1,391	2,213	524		
1966	925	1,455	2,380	537		
1965	885	1,403	2,288	507		
1964	818	1,340	2,158	485		
1963	802	1,197	1,999	464		
1962	789	1,147	1,936	454		
1961	748	1,080	1,828	440		
1960	731	1,112	1,843	434	7,823	1,698
WISCONSIN						
1982	3,459	[4]	[4]		4,765	
1981	3,582	537	4,119		4,740	
1980	3,491	668	4,159	616	4,728	1,456
1979	3,594	768	4,362	644	4,660	1,501
1978	3,151	656	3,807	635	4,631	1,470
1977	2,899	533	3,432	612	4,613	1,412
1976	NA	NA	NA	587	4,585	1,346
1975	2,657	445	3,102	518	4,570	1,184
1974	3,015	559	3,574	605		
1973	3,045	622	3,667	631		
1972	2,817	640	3,457	615		
1971	2,621	612	3,233	575		
1970	2,550	580	3,130	566	4,426	1,253
1969	2,717	575	3,292	582		
1968	2,438	589	3,027	556		
1967	2,302	531	2,833	524		
1966	2,339	581	2,920	537		
1965	2,221	566	2,787	507		
1964	2,080	544	2,624	485		
1963	1,942	519	2,461	464		
1962	1,840	515	2,355	454		
1961	1,766	487	2,253	440		
1960	1,763	462	2,225	434	3,952	858

(Table 17 continued on next page)

(Table 17 continued)

MINNESOTA

Year	Production[1]			Consumption		
	Paper	Board: all grades[2]	Total	Per capita[3]	Residential population	Total
				Pounds	Thousand	
1982	856	[4]	[4]		4,133	
1981	816	[4]	[4]		4,113	
1980	[4]	[4]	1,283	616	4,083	1,258
1979	[4]	[4]	1,680	644	4,038	1,300
1978	[4]	[4]	1,444	635	4,005	1,272
1977	808	656	1,464	612	3,980	1,218
1976	NA	NA	NA	587	3,957	1,161
1975	620	605	1,225	518	3,926	1,017
1974	664	632	1,296	605		
1973	652	654	1,306	631		
1972	657	627	1,284	615		
1971	606	591	1,197	575		
1970	609	553	1,162	566	3,814	1,079
1969	608	557	1,165	582		
1968	574	574	1,148	556		
1967	546	526	1,072	524		
1966	530	567	1,097	537		
1965	484	575	1,059	507		
1964	453	535	988	485		
1963	415	494	909	464		
1962	405	488	893	454		
1961	367	483	850	440		
1960	374	536	910	434	3,414	741

[1] U.S. Department of Commerce, Bureau of the Census, Current Industrial Report Series M26A.

[2] Board: all grades equals the total production of paperboard, wet machine board, and construction paper and board.

[3] Ulrich (1983).

[4] Non-disclosure.

Table 18.--Woodpulp production and consumption in Michigan, Wisconsin, and Minnesota[1/]

(In thousand short tons)

Year	Production	Consumption		
	total	Own	Purchase	Total
MICHIGAN				
1982	849	615	463	1,078
1981	967	738	488	1,226
1980	958	885	645	1,530
1979	955	905	734	1,639
1978	923	882	545	1,427
1977	862	834	466	1,300
1976	805	774	466	1,240
1975	649	672	387	1,059
1974	873	902	531	1,433
1973	594	865	534	1,399
1972	615	807	517	1,324
1971	573	789	415	1,204
1970	587	839	425	1,264
1969	589	850	475	1,325
1968	496	757	367	1,124
1967	576	835	340	1,175
1966	590	763	443	1,206
1965	606	806	398	1,204
1964	570	727	407	1,134
1963	549			
1962	500			
1961	477			
1960	515			
WISCONSIN				
1982	1,541	1,778	735	2,513
1981	1,688	1,910	817	2,727
1980	1,750	1,655	979	2,634
1979	1,711	1,825	975	2,800
1978	1,486	1,625	805	2,430
1977	1,471	1,637	774	2,411
1976	1,489	1,622	804	2,426
1975	1,363	1,530	705	2,235
1974	1,537	1,693	880	2,573
1973	1,619	1,818	886	2,704
1972	1,596	1,758	793	2,551
1971	1,610	1,779	652	2,431
1970	1,545	1,700	659	2,359
1969	1,657	1,816	646	2,462
1968	1,444	1,638	589	2,227
1967	1,424	1,550	559	2,109
1966	1,471	1,633	472	2,105
1965	1,448	1,606	435	2,041
1964	1,407	1,515	384	1,899
1963	1,400			
1962	1,340			
1961	1,290			
1960	1,257			

(Table 18 continued on next page)

(Table 18 continued)

MINNESOTA

Year	Production total	Consumption		
		Own	Purchase	Total
1982	799[2/]	[3/]	[3/]	891
1981	771	[3/]	[3/]	958
1980	847	819	226	1,045
1979	927	899	201	1,100
1978	946	941	185	1,126
1977	932	916	194	1,109
1976	907	899	167	1,066
1975	790	773	140	913
1974	877	908[2/]	167[2/]	1,075
1973	792	836[2/]	108[2/]	943
1972	761	859[2/]	93[2/]	952
1971	738	791[2/]	124[2/]	915
1970	706	755[2/]	124[2/]	880
1969	736	796[2/]	129[2/]	925
1968	701	576[2/]	115[2/]	691
1967	652	687[2/]	106[2/]	792
1966	701	479[2/]	104[2/]	583
1965	696	482[2/]	103[2/]	585
1964	789[2/]	636	93	729
1963	601			
1962	667			
1961	654			
1960	622			

[1/] U.S. Department of Commerce, Bureau of the Census, Current Industrial Report Series M26A.

[2/] Minnesota's figures were not disclosed in these categories; therefore, West North Central figures are shown, in which Minnesota represents a large share.

[3/] Non-disclosure.

Table 19.--Wastepaper utilization by paper and board mills in Michigan, Wisconsin, and Minnesota[1/]

(In thousand short tons)

Year	Paper & board produced	Utilization rate[2/]	Wastepaper used
	MICHIGAN		
1981	[3/]	23.9	NA
1980	2,404	23.4	563
1979	2,538	23.8	604
1978	2,542	23.7	602
1977	2,441	23.3	569
1976	NA	23.3	NA
1975	1,855	22.9	425
1974	2,474	23.6	584
1973	2,590	23.5	609
1972	2,414	22.5	543
1971	2,275	22.8	519
1970	2,235	22.8	510
	WISCONSIN		
1981	4,119	23.9	984
1980	4,159	23.4	973
1979	4,362	23.8	1,038
1978	3,807	23.7	902
1977	3,432	23.3	800
1976	NA	23.3	NA
1975	3,102	22.9	710
1974	3,574	23.6	843
1973	3,667	23.5	862
1972	3,457	22.5	778
1971	3,233	22.8	737
1970	3,130	22.8	714
	MINNESOTA		
1981	[3/]	23.9	NA
1980	1,283	23.4	300
1979	1,680	23.8	400
1978	1,444	23.7	342
1977	1,464	23.3	341
1976	NA	23.3	NA
1975	1,225	22.9	281
1974	1,296	23.6	306
1973	1,306	23.5	307
1972	1,284	22.5	289
1971	1,197	22.8	273
1970	1,162	22.8	265

[1/] American Paper Institute, Statistics of Paper, Paperboard and Woodpulp.

[2/] The utilization rate equals the ratio of recyclable paper consumption to total production of paper and board.

[3/] Non-disclosure.

Table 20.--Pulpwood production in the Lake States[1/]

(All wood, in thousand standard cords)

Year	Michigan	Wisconsin	Minnesota	Total
1982	1,750	2,286	1,484	5,520
1981	1,837	2,389	1,370	5,596
1980	1,969	2,362	1,333	5,664
1979	1,980	2,109	1,459	5,548
1978	1,675	1,895	1,338	4,908
1977	1,595	1,816	1,333	4,744
1976	1,541	1,840	1,308	4,689
1975	1,281	1,505	1,359	4,145
1974	1,842	2,053	1,578	5,473
1973	1,586	1,758	1,377	4,721
1972	1,396	1,537	1,354	4,287
1971	1,267	1,552	1,196	4,015
1970	1,406	1,656	1,224	4,286
1969	1,302	1,450	1,192	3,944
1968	1,168	1,297	1,087	3,552
1967	1,344	1,416	1,205	3,965
1966	1,570	1,536	1,174	4,280
1965	1,365	1,253	1,018	3,636
1964	1,321	1,244	1,062	3,627
1963	1,297	1,302	1,063	3,662
1962	1,223	1,141	978	3,342
1961	1,107	1,078	968	3,153
1960	1,237	1,052	1,048	3,337

[1/] USDA Forest Service, Pulpwood Production in the North-Central Region by County.

Table 21.--Pulpwood receipts in the Lake States[1/]

(All wood, in thousand standard cords)

Year	Michigan	Wisconsin	Minnesota	Total
1982	1,388	2,978	1,298	5,664
1981	1,448	3,154	1,164	5,766
1980	1,493	3,266	1,097	5,856
1979	1,491	3,067	1,295	5,853
1978	1,332	2,676	1,218	5,226
1977	1,231	2,596	1,209	5,036
1976	1,115	2,713	1,177	5,005
1975	843	2,344	1,226	4,413
1974	1,324	3,135	1,392	5,851
1973	1,198	2,696	1,222	5,116
1972	931	2,450	1,224	4,605
1971	699	2,581	1,064	4,344
1970	806	2,821	1,058	4,685
1969	772	2,513	1,082	4,367
1968	774	2,226	992	3,992
1967	773	2,729	958	4,460
1966	1,003	2,701	1,140	4,844
1965	825	2,290	912	4,027
1964	791	2,271	938	4,000
1963	742	2,429	921	4,092
1962	679	2,124	828	3,631
1961	700	1,972	784	3,456
1960	810	2,115	787	3,712

[1/] USDA Forest Service, Pulpwood Production in the North-Central Region by County.

Table 22.--Lake States pulpwood imports and exports[1/]

(All wood, in thousand standard cords)

Year	Imports			Exports
	Other States	Canada	Total	Outside region
1982	147	53	200	56
1981	180	90	270	101
1980	203	110	313	121
1979	309	113	422	118
1978	272	109	381	64
1977	255	110	365	71
1976	236	132	368	53
1975	205	95	300	31
1974	294	132	426	48
1973	332	150	482	34
1972	244	118	362	48
1971	246	126	372	43
1970	260	181	441	43
1969	268	207	475	52
1968	231	254	485	44
1967	239	292	531	36
1966	264	332	596	32
1965	136	298	434	44
1964	135	271	406	32
1963	153	309	462	32
1962	108	206	314	26
1961	44	303	347	43
1960	82	347	429	54

[1/] USDA Forest Service, Pulpwood Production in the North-Central Region by County.

Table 23.--Lake States pulpwood production for flakeboard plants[1/]

(In thousand cords)

	1981	1982
Roundwood		
Aspen	382	554
Other species	54	48
Residue	60	73
Total	496	675

[1/] Blyth and Smith (1984a). Flakeboard production equals particleboard production, as defined in this study.

Table 24.--Pulpwood production in Michigan, Wisconsin, and Minnesota by state of destination[1/]

(All wood, in thousand standard cords)

Year	Destination				Total
	Michigan	Wisconsin	Minnesota	Outside region	
			MICHIGAN		
1982	1,341	396	0[2/]	15	1,752
1981	1,402	419	0	17	1,838
1980	1,442	490	0	36	1,968
1979	1,428	516	0	37	1,981
1978	1,248	404	0	23	1,675
1977	1,158	407	0	29	1,594
1976	1,081	434	0	26	1,541
1975	814	449	0	17	1,280
1974	1,290	534	0	19	1,843
1973	1,131	418	0	36	1,585
1972	917	470	0	14	1,401
1971	688	567	0	12	1,267
1970	785	610	0	11	1,406
1969	752	537	0	13	1,302
1968	702	455	0	11	1,168
1967	684	660	0	0	1,344
1966	901	666	1	2	1,570
1965	750	608	0	7	1,365
1964	730	588	0	3	1,321
1963	664	628	0	0	1,292
1962	677	540	0	7	1,224
1961	628	464	0	14	1,106
1960	727	510	0	0	1,237
			WISCONSIN		
1982	28	2,231	26	0	2,286
1981	26	2,320	34	9	2,389
1980	35	2,298	18	12	2,362
1979	47	2,024	21	18	2,109
1978	70	1,779	26	20	1,895
1977	64	1,714	26	12	1,816
1976	24	1,784	23	9	1,840
1975	19	1,460	20	6	1,505
1974	25	2,004	14	10	2,053
1973	55	1,671	14	18	1,758
1972	2	1,493	28	14	1,437
1971	0	1,502	35	15	1,552
1970	10	1,627	11	8	1,656
1969	9	1,412	17	12	1,450
1968	4	1,259	22	12	1,297
1967	0	1,337	15	14	1,416
1966	3	1,501	13	19	1,536
1965	1	1,225	8	19	1,253
1964	2	1,207	19	16	1,244
1963	2	1,262	20	18	1,302
1962	1	1,114	15	10	1,140
1961	1	1,050	14	14	1,078
1960	0	1,008	19	25	1,052

(Table 24 continued on next page)

(Table 24 continued)

Year	MINNESOTA Destination				Total
	Michigan	Wisconsin	Minnesota	Outside region	
1982	0	179	1,264	41	1,484
1981	0	177	1,119	75	1,371
1980	0	216	1,044	73	1,333
1979	0	169	1,226	63	1,458
1978	0	162	1,155	21	1,338
1977	0	154	1,149	30	1,333
1976	0	182	1,109	18	1,309
1975	0	178	1,173	8	1,359
1974	0	262	1,297	19	1,578
1973	0	194	1,152	30	1,376
1972	0	166	1,168	20	1,354
1971	0	188	992	16	1,196
1970	0	219	981	24	1,224
1969	0	188	977	27	1,192
1968	0	166	900	21	1,087
1967	0	299	884	22	1,205
1966	0	193	970	11	1,174
1965	0	159	842	18	1,019
1964	0	193	856	13	1,062
1963	0	221	828	14	1,063
1962	1	216	753	9	979
1961	0	240	712	15	967
1960	0	308	711	29	1,048

1/ USDA Forest Service, Pulpwood Production in the North-Central Region by County.

2/ Less than 500 standard cords.

Table 25.--Pulpwood production in the Lake States, Michigan, Wisconsin, and Minnesota by species group[1/]

(In thousand standard cords)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
				LAKE STATES			
1982	881	759	2,382	1,042	5,063	457	5,520
1981	751	680	2,418	1,190	5,039	557	5,596
1980	763	776	2,277	1,309	5,125	539	5,664
1979	836	664	2,298	1,195	4,992	555	5,548
1978	786	661	1,959	1,021	4,427	481	4,908
1977	702	679	1,925	936	4,242	602	4,744
1976	710	661	1,857	1,006	4,234	455	4,689
1975	646	754	1,640	638	3,677	468	4,145
1974	760	696	2,307	1,196	4,959	514	5,473
1973	640	607	2,037	976	4,260	461	4,721
1972	690	546	1,902	797	3,935	352	4,287
1971	717	493	1,891	605	3,706	309	4,015
1970	720	592	1,967	659	3,938	348	4,286
1969	660	479	1,963	555	3,657	287	3,944
1968	607	484	1,753	449	3,293	259	3,552
1967	569	666	1,976	539	3,750	215	3,965
1966	721	666	2,198	520	4,105	175	4,280
1965	611	657	1,780	444	3,492	144	3,636
1964	570	707	1,729	493	3,499	128	3,627
1963	552	782	1,708	488	3,530	132	3,662
1962	573	696	1,579	430	3,278	64	3,342
1961	515	757	1,457	382	3,111	42	3,153
1960	537	841	1,601	324	3,303	33	3,337
				MICHIGAN			
1982	243	269	632	485	1,629	121	1,750
1981	217	224	652	578	1,671	166	1,837
1980	250	256	705	605	1,816	153	1,969
1979	341	188	709	564	1,802	178	1,980
1978	266	197	586	479	1,528	147	1,675
1977	249	227	532	395	1,403	192	1,595
1976	267	206	491	389	1,353	188	1,541
1975	228	181	436	254	1,099	182	1,281
1974	250	182	706	508	1,646	196	1,842
1973	203	178	603	426	1,410	176	1,586
1972	228	151	529	345	1,253	143	1,396
1971	235	142	547	220	1,144	123	1,267
1970	240	189	596	229	1,254	152	1,406
1969	207	148	606	219	1,180	122	1,302
1968	205	148	541	184	1,078	90	1,168
1967	193	227	646	210	1,276	68	1,344
1966	250	262	776	207	1,495	75	1,570
1965	224	205	704	181	1,314	51	1,365
1964	198	217	675	184	1,274	47	1,321
1963	174	274	662	154	1,264	33	1,297
1962	184	251	601	165	1,201	22	1,223
1961	156	260	558	112	1,086	21	1,107
1960	188	295	669	83	1,235	2	1,237

(Table 25 continued on next page)

(Table 25 continued)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
			WISCONSIN				
1982	473	193	884	494	2,043	243	2,286
1981	398	187	965	548	2,098	291	2,389
1980	369	190	873	641	2,073	289	2,362
1979	341	165	751	593	1,849	259	2,109
1978	339	169	669	494	1,671	224	1,895
1977	283	154	696	486	1,619	297	1,816
1976	274	166	693	539	1,672	168	1,840
1975	227	186	588	327	1,327	178	1,505
1974	278	164	797	608	1,847	206	2,053
1973	232	116	761	472	1,581	177	1,758
1972	246	106	684	380	1,416	121	1,537
1971	268	111	736	320	1,435	117	1,552
1970	259	141	771	372	1,543	113	1,656
1969	216	116	697	301	1,330	120	1,450
1968	199	111	629	241	1,180	117	1,297
1967	174	105	739	287	1,305	111	1,416
1966	215	145	810	281	1,451	85	1,536
1965	206	129	608	222	1,165	88	1,253
1964	168	132	603	265	1,168	76	1,244
1963	170	138	613	283	1,204	98	1,302
1962	188	110	572	229	1,099	42	1,141
1961	154	138	530	235	1,057	21	1,078
1960	124	126	540	230	1,020	31	1,052
			MINNESOTA				
1982	165	297	866	63	1,391	93	1,484
1981	136	269	801	64	1,270	100	1,370
1980	144	330	699	63	1,236	97	1,333
1979	154	311	838	38	1,341	118	1,459
1978	181	295	704	48	1,228	110	1,338
1977	170	298	697	55	1,220	113	1,333
1976	169	289	673	78	1,209	99	1,308
1975	191	387	616	57	1,251	108	1,359
1974	232	350	804	80	1,466	112	1,578
1973	205	313	673	78	1,269	108	1,377
1972	216	289	689	72	1,266	88	1,354
1971	214	240	608	65	1,127	69	1,196
1970	221	262	600	58	1,141	83	1,224
1969	237	215	660	35	1,147	45	1,192
1968	203	225	583	24	1,035	52	1,087
1967	202	334	591	42	1,169	36	1,205
1966	256	259	612	32	1,159	15	1,174
1965	181	323	468	41	1,013	5	1,018
1964	204	358	451	44	1,057	5	1,062
1963	208	370	433	51	1,062	1	1,063
1962	201	335	406	36	978	0[2/]	978
1961	205	359	369	35	968	0	968
1960	225	420	392	11	1,048	0	1,048

1/ USDA Forest Service, Pulpwood Production in the North-Central Region by County.

2/ Less than 500 standard cords.

Table 26.--Pulpwood receipts in Michigan, Wisconsin, and Minnesota by state of origin[1/]

(All wood, in thousand standard cords)

Year	Origin					
	Michigan	Wisconsin	Minnesota	Other States	Canada	Total
MICHIGAN						
1982	1,341	28	0[2/]	16	3	1,388
1981	1,402	26	0	16	4	1,448
1980	1,442	35	0	13	3	1,493
1979	1,428	47	0	14	2	1,491
1978	1,248	70	0	10	4	1,332
1977	1,158	64	0	9	0	1,231
1976	1,081	24	0	7	3	1,115
1975	814	19	0	10	0	843
1974	1,290	25	0	9	0	1,324
1973	1,131	55	0	12	0	1,198
1972	917	2	0	12	0	931
1971	688	0	0	11	0	699
1970	785	10	0	10	1	806
1969	752	9	0	9	2	772
1968	702	4	0	7	61	774
1967	684	0	0	4	85	773
1966	901	3	0	2	97	1,003
1965	750	1	0	0	74	825
1964	730	2	0	0	59	791
1963	669	2	0	0	71	742
1962	677	1	1	0	0	679
1961	628	1	0	0	71	700
1960	727	0	0	0	83	810
WISCONSIN						
1982	396	2,231	179	131	42	2,978
1981	419	2,320	177	164	75	3,154
1980	490	2,298	216	170	92	3,266
1979	516	2,024	169	266	92	3,067
1978	404	1,779	162	242	88	2,676
1977	407	1,714	154	227	95	2,596
1976	434	1,784	182	203	110	2,713
1975	449	1,460	178	177	80	2,344
1974	534	2,004	262	269	67	3,135
1973	419	1,671	194	291	123	2,696
1972	470	1,493	166	230	92	2,450
1971	567	1,502	188	234	90	2,581
1970	610	1,627	219	249	115	2,821
1969	537	1,412	188	257	119	2,513
1968	455	1,259	166	223	124	2,226
1967	660	1,387	299	234	149	2,729
1966	666	1,501	193	185	156	2,701
1965	608	1,225	159	135	163	2,290
1964	588	1,207	193	135	149	2,271
1963	628	1,262	221	153	165	2,429
1962	540	1,114	216	108	146	2,124
1961	464	1,050	240	44	174	1,972
1960	510	1,008	308	82	207	2,115

(Table 26 continued on next page)

(Table 26 continued)

Year	MINNESOTA Origin					
	Michigan	Wisconsin	Minnesota	Other States	Canada	Total
1982	0	26	1,264	0	8	1,298
1981	0	34	1,119	0	11	1,164
1980	0	18	1,044	20	15	1,097
1979	0	21	1,226	29	19	1,295
1978	0	26	1,155	20	17	1,218
1977	0	26	1,149	19	15	1,209
1976	0	23	1,109	26	19	1,177
1975	0	20	1,173	18	15	1,226
1974	0	14	1,297	16	65	1,392
1973	0	14	1,152	29	27	1,222
1972	0	28	1,168	2	26	1,224
1971	0	35	992	1	36	1,064
1970	0	11	981	1	65	1,058
1969	0	17	977	2	86	1,082
1968	0	22	900	1	69	992
1967	0	15	884	1	58	958
1966	1	13	970	77	79	1,140
1965	0	8	842	1	61	912
1964	0	19	856	0	63	938
1963	0	20	828	0	73	921
1962	0	15	753	0	60	828
1961	0	14	712	0	58	784
1960	0	19	711	0	57	787

1/ USDA Forest Service, Pulpwood Production in the North-Central Region by County.

2/ Less than 500 standard cords.

Table 27.--Pulpwood receipts in the Lake States, Michigan, Wisconsin, and Minnesota by species group[1/]

(In thousand standard cords)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
				LAKE STATES			
1982	882	735	2,370	1,042	5,029	637	5,666
1981	763	650	2,393	1,186	4,992	775	5,767
1980	782	722	2,257	1,306	5,067	789	5,856
1979	886	659	2,258	1,186	4,989	863	5,852
1978	827	658	1,958	1,010	4,453	772	5,225
1977	738	691	1,909	931	4,269	771	5,040
1976	756	697	1,852	1,002	4,307	698	5,005
1975	701	794	1,639	634	3,768	647	4,415
1974	826	745	2,308	1,198	5,077	774	5,851
1973	676	710	2,027	959	4,372	744	5,116
1972	736	631	1,910	796	4,073	533	4,606
1971	783	570	1,894	607	3,854	491	4,345
1970	838	685	1,977	659	4,159	525	4,684
1969	803	581	1,969	557	3,910	457	4,367
1968	744	645	1,764	449	3,602	392	3,994
1967	712	884	1,990	543	4,129	332	4,461
1966	823	955	2,225	513	4,516	251	4,767
1965	729	861	1,797	431	3,818	209	4,027
1964	670	911	1,739	484	3,804	198	4,002
1963	688	1,014	1,722	481	3,905	188	4,093
1962	681	840	1,589	422	3,532	100	3,632
1961	626	967	1,467	372	3,432	24	3,456
1960	680	1,073	1,624	320	3,697	15	3,712
				MICHIGAN			
1982	198	202	493	379	1,272	116	1,388
1981	170	160	486	467	1,283	165	1,448
1980	188	156	525	467	1,336	157	1,493
1979	217	122	526	428	1,293	197	1,490
1978	208	143	423	382	1,156	176	1,332
1977	197	160	370	316	1,043	190	1,233
1976	202	104	327	310	943	171	1,114
1975	162	57	288	204	711	133	844
1974	151	85	481	447	1,164	160	1,324
1973	134	91	404	414	1,043	154	1,197
1972	127	70	322	317	835	96	932
1971	115	39	298	187	639	62	701
1970	152	51	332	182	717	88	805
1969	116	38	358	173	685	86	771
1968	133	99	328	158	718	56	774
1967	117	129	323	167	736	37	773
1966	143	127	526	167	963	41	1,004
1965	114	110	436	147	807	18	825
1964	107	107	429	146	789	3	792
1963	84	127	399	132	742	0[2/]	742
1962	97	64	387	131	679	0	679
1961	109	143	351	97	700	0	700
1960	128	181	431	70	810	0	810

(Table 27 continued on next page)

(Table 27 continued)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
			WISCONSIN				
1982	544	305	1,092	606	2,547	431	2,978
1981	488	307	1,182	666	2,643	511	3,154
1980	495	338	1,119	792	2,744	522	3,266
1979	544	274	999	727	2,544	524	3,068
1978	472	275	888	595	2,230	446	2,676
1977	402	292	915	564	2,173	424	2,597
1976	423	373	926	617	2,339	374	2,713
1975	377	419	791	376	1,963	381	2,344
1974	490	416	1,109	674	2,689	446	3,135
1973	387	410	1,005	466	2,268	428	2,696
1972	443	364	902	402	2,111	339	2,450
1971	514	375	1,011	348	2,248	333	2,581
1970	498	481	1,088	413	2,480	341	2,821
1969	456	426	978	341	2,201	313	2,514
1968	405	420	860	264	1,949	278	2,227
1967	416	590	1,116	349	2,471	259	2,730
1966	473	613	1,112	314	2,512	189	2,701
1965	410	553	899	245	2,107	183	2,290
1964	350	583	855	295	2,083	189	2,272
1963	414	653	877	299	2,243	187	2,430
1962	395	591	784	255	2,025	100	2,125
1961	330	637	741	240	1,948	24	1,972
1960	388	688	785	239	2,100	15	2,115
			MINNESOTA				
1982	140	228	785	57	1,210	90	1,300
1981	105	183	725	53	1,066	99	1,165
1980	99	228	613	47	987	110	1,097
1979	125	263	733	31	1,152	142	1,294
1978	147	240	647	33	1,067	150	1,217
1977	139	239	624	51	1,053	157	1,210
1976	131	220	599	75	1,025	153	1,178
1975	162	318	560	54	1,094	133	1,227
1974	185	244	718	77	1,224	168	1,392
1973	155	209	618	79	1,061	162	1,223
1972	166	197	686	77	1,126	98	1,224
1971	154	156	585	72	967	96	1,063
1970	188	153	557	64	962	96	1,058
1969	231	117	633	43	1,024	58	1,082
1968	206	126	576	27	935	58	993
1967	179	165	551	27	922	36	958
1966	207	215	587	32	1,041	21	1,062
1965	205	198	462	39	904	8	912
1964	213	221	455	43	932	6	938
1963	190	234	446	50	920	1	921
1962	189	185	418	36	828	0	828
1961	187	187	375	35	784	0	784
1960	164	204	408	11	787	0	787

1/ USDA Forest Service, Pulpwood Production in the North-Central Region by County.

2/ Less than 500 standard cords.

Table 28.--Pulpwood imports into Michigan, Wisconsin, and Minnesota by species group[1/]

(In thousand standard cords)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
			MICHIGAN				
1982	3	2	0[2/]	0[2/]	5	42	47
1981	3	3	0	0	6	40	46
1980	2	5	0	1	8	43	51
1979	3	12	1	1	17	45	62
1978	9	20	1	3	33	51	84
1977	15	24	1	3	43	31	74
1976	5	1	1	5	12	22	34
1975	2	4	3	3	12	17	29
1974	1	3	5	12	21	13	34
1973	1	3	5	29	38	30	68
1972	0	0	0	2	2	11	13
1971	0	1	0	0	1	11	12
1970	0	2	1	0	3	18	21
1969	0	1	2	0	3	15	18
1968	0	60	4	0	64	7	71
1967	0	82	4	0	86	4	90
1966	0	76	25	1	102	1	103
1965	0	64	10	0	74	0	74
1964	0	57	4	0	61	0	61
1963	0	68	5	0	73	0	73
1962	0	1	1	0	2	0	2
1961	0	71	0	0	71	0	71
1960	0	72	11	0	83	0	83
			WISCONSIN				
1982	80	114	226	114	534	212	746
1981	96	122	249	122	589	246	835
1980	129	152	264	156	701	267	968
1979	205	122	266	143	736	308	1,044
1978	142	131	233	112	618	279	897
1977	134	162	231	85	612	271	883
1976	154	208	245	85	692	236	928
1975	152	238	216	55	661	224	885
1974	214	255	318	80	867	264	1,131
1973	157	295	252	32	736	290	1,026
1972	197	259	242	30	728	230	958
1971	246	265	296	33	840	239	1,079
1970	239	339	322	46	946	248	1,194
1969	240	310	290	46	886	216	1,102
1968	206	309	243	27	785	183	968
1967	242	484	378	67	1,171	172	1,343
1966	257	468	310	40	1,075	125	1,200
1965	204	423	294	34	955	110	1,065
1964	183	449	269	39	940	123	1,063
1963	245	515	285	22	1,067	101	1,168
1962	208	481	228	35	952	59	1,011
1961	176	500	225	15	916	7	923
1960	265	562	263	14	1,104	3	1,107

(Table 28 continued on next page)

(Table 28 continued)

MINNESOTA

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
1982	6	4	18	1	29	5	34
1981	2	3	32	1	38	8	46
1980	0	7	18	0	25	28	53
1979	3	5	16	0	24	43	67
1978	2	4	12	0	18	45	63
1977	2	0	11	0	13	48	61
1976	2	0	11	0	13	55	68
1975	16	0	11	0	27	27	54
1974	19	0	6	6	31	64	95
1973	1	1	9	4	15	56	71
1972	0	1	35	6	42	13	55
1971	9	0	24	7	40	30	70
1970	38	2	9	7	56	20	76
1969	58	3	16	10	87	18	105
1968	48	3	21	6	78	14	92
1967	35	9	8	7	59	15	74
1966	8	65	10	0	83	10	93
1965	48	6	10	0	64	6	70
1964	48	7	24	0	79	3	82
1963	45	18	30	0	93	0	93
1962	43	7	25	0	75	0	75
1961	41	8	23	0	72	0	72
1960	39	7	29	0	75	0	75

1/ USDA Forest Service, Pulpwood Production in the North-Central Region by County.

2/ Less than 500 standard cords.

Table 29.--Pulpwood exports from Michigan, Wisconsin, and Minnesota by species group[1/]

(In thousand standard cords)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
			MICHIGAN				
1982	48	69	139	107	363	47	410
1981	50	67	167	111	395	41	436
1980	64	105	180	139	488	39	527
1979	127	79	184	138	528	26	554
1978	68	74	164	99	405	22	427
1977	68	91	163	81	403	33	436
1976	71	103	165	82	421	39	460
1975	68	129	150	52	399	67	466
1974	100	100	230	74	504	49	553
1973	70	88	204	40	402	52	454
1972	102	86	207	31	426	58	484
1971	120	90	249	33	492	72	564
1970	88	140	265	47	540	82	622
1969	91	112	250	47	500	51	551
1968	72	110	217	26	425	41	466
1967	76	179	327	44	626	34	660
1966	108	210	276	40	634	35	669
1965	110	160	278	34	582	33	615
1964	90	169	249	39	547	44	591
1963	90	215	269	22	596	33	629
1962	86	189	215	35	525	22	547
1961	47	188	208	14	457	21	478
1960	59	185	250	14	508	2	510
			WISCONSIN				
1982	9	3	18	2	32	23	55
1981	5	3	32	4	44	25	69
1980	3	5	18	4	30	34	64
1979	3	12	18	9	42	43	85
1978	9	25	14	11	59	57	116
1977	15	24	13	7	59	44	103
1976	5	1	12	8	26	30	56
1975	2	5	13	4	24	21	45
1974	1	2	6	16	25	25	50
1973	1	3	7	37	48	39	87
1972	0[2/]	0	25	8	33	11	44
1971	0	0	22	5	27	23	50
1970	0	0	5	4	9	21	30
1969	0	0	9	5	14	24	38
1968	0	0	12	4	16	22	38
1967	0	0	1	4	5	24	29
1966	0	0	7	8	15	20	35
1965	0	0	2	10	12	15	27
1964	1	0	17	8	26	11	37
1963	1	0	21	6	28	12	40
1962	0	0	16	9	25	1	26
1961	0	0	15	9	24	4	28
1960	1	0	18	6	25	20	45

(Table 29 continued on next page)

(Table 29 continued)

MINNESOTA

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total roundwood	Residue	All wood
1982	32	73	100	8	213	8	221
1981	33	90	108	12	243	9	252
1980	45	109	104	17	275	15	290
1979	32	53	121	7	213	19	232
1978	36	59	69	15	179	4	183
1977	33	59	84	4	180	4	184
1976	43	69	85	1	198	2	200
1975	45	69	68	3	185	1	186
1974	66	106	91	9	272	8	280
1973	51	104	63	4	222	2	224
1972	50	93	38	2	183	3	186
1971	69	85	47	0	201	5	206
1970	72	111	52	1	236	7	243
1969	64	101	43	2	210	5	215
1968	45	104	28	2	179	8	187
1967	58	177	49	2	286	15	301
1966	57	109	34	0	200	3	203
1965	25	132	16	2	175	3	178
1964	38	145	19	2	204	2	206
1963	63	154	16	1	234	0	234
1962	56	157	13	1	227	0	227
1961	59	179	17	1	256	0	256
1960	100	224	13	0	337	0	337

1/ USDA Forest Service, Pulpwood Production in the North-Central Region by County.

2/ Less than 500 standard cords.

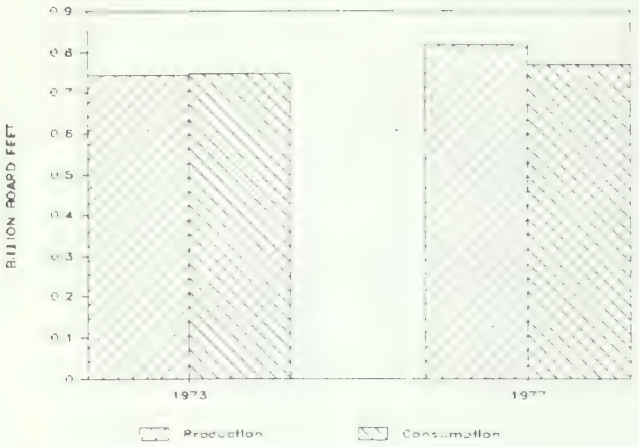


Figure 29.—*Hardwood lumber production and consumption in the Lake States.*

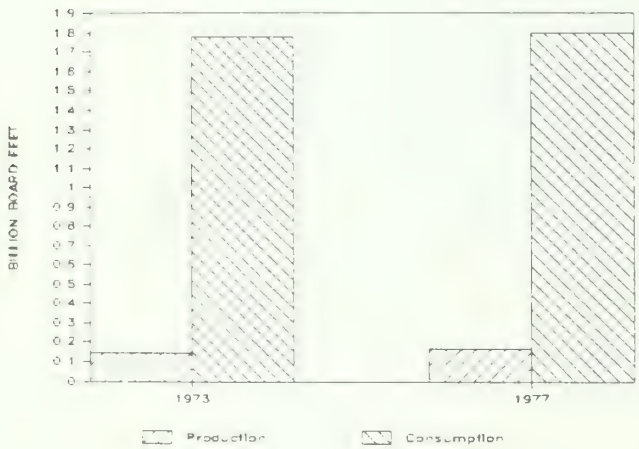


Figure 30.—*Softwood lumber production and consumption in the Lake States.*

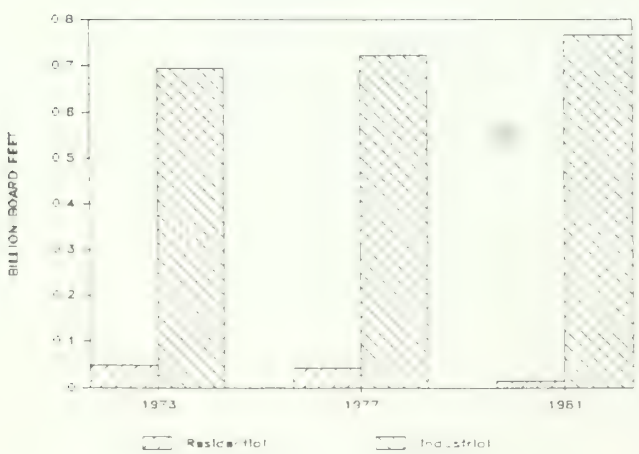


Figure 31.—*Hardwood lumber consumption in the Lake States by end use.*

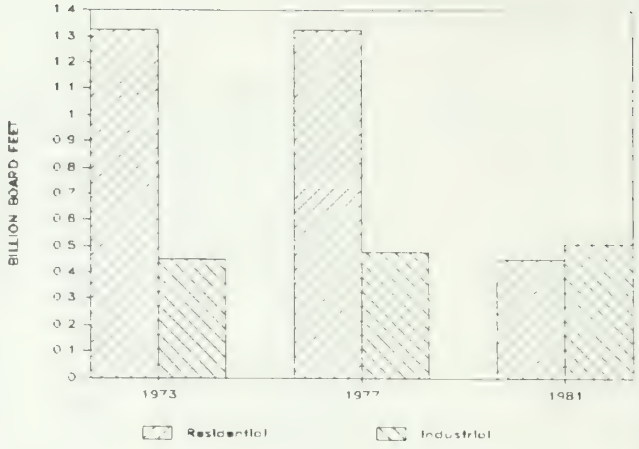


Figure 32.—*Softwood lumber consumption in the Lake States by end use.*

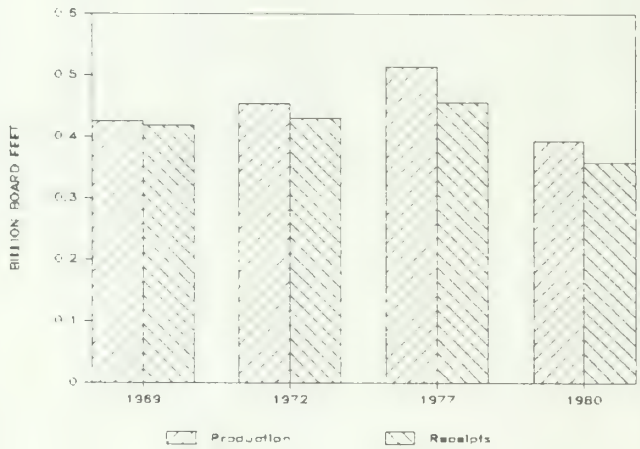


Figure 33.—*Saw log production and receipts in Michigan.*

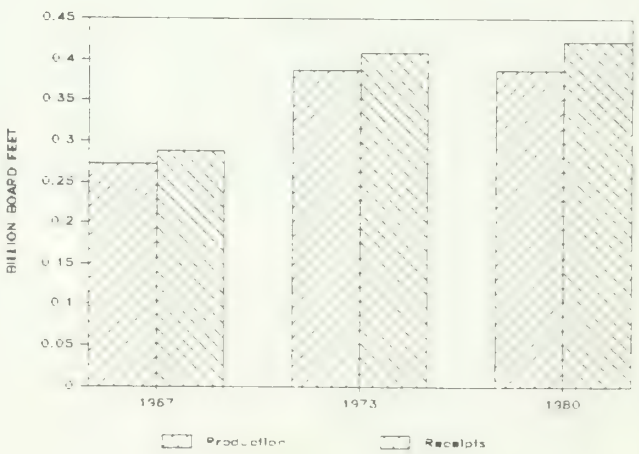


Figure 34.—*Saw log production and receipts in Wisconsin.*

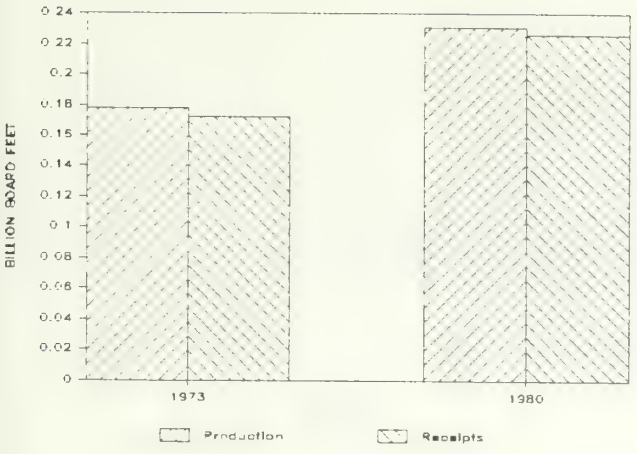


Figure 35.—*Saw log production and receipts in Minnesota.*

Table 30.--Lumber production in the Lake States, Michigan, and Wisconsin[1/]

(In million board feet, lumber tally)

Year	Softwood	Hardwood	Total[2/]
	LAKE STATES		
1979[3/]	182	831	1,014
1978	189	828	1,018
1977	168	816	984
1976	151	735	887
1975	141	666	807
1974	141	703	844
1973	145	754	899
1972	119	688	807
1971	116	685	802
1970	124	704	827
1969	158	656	814
1968	150	674	823
1967	131	654	785
1966	142	627	769
1965	142	644	786
1964	144	645	789
1963	190	547	737
1962		476	
1961		471	
	MICHIGAN		
1979[3/]	40	334	374
1978	39	326	365
1977	31	319	350
1976	37	297	334
1975	39	278	317
1974	37	314	351
1973	43	348	391
1972	39	347	386
1971	37	366	403
1970	42	365	407
1969	67	321	388
1968	64	335	399
1967	48	320	368
1966	54	295	349
1965	56	314	370
1964	63	314	377
1963	77	293	370
1962	42	231	273
1961	51	222	273
	WISCONSIN		
1979[3/]	81	418	499
1978	88	419	507
1977	78	416	494
1976	66	357	423
1975	56	314	370
1974	60	307	367
1973	57	320	377
1972	38	266	304
1971	39	234	273
1970	41	245	286
1969	46	241	287
1968	41	253	294
1967	42	244	286
1966	48	243	291
1965	50	249	299
1964	45	248	293
1963	78	178	256
1962	41	176	217
1961	39	189	228

[1/] U.S. Department of Commerce, Bureau of the Census, Current Industrial Report Series MA-24T.

[2/] Minnesota's production was estimated by taking a share of the production in the West North Central Division. See table 31.

[3/] State data was discontinued in the North Central Region after 1979.

Table 31.--Lumber production in Minnesota and West North Central division[1/]

(In million board feet, lumber tally)

Year	Softwood		Hardwood		Total	
	West North Central	Minnesota	West North Central	Minnesota	West North Central	Minnesota
1982	70		[3/]			
1981	75		[3/]			
1980	273	60	330	73	603	133
1979	279	61	360	79	639	141
1978	284	62	379	83	663	146
1977	270	59	367	81	637	140
1976	219	48	370	81	589	130
1975	210	46	337	74	547	120
1974	200	44	374	82	574	126
1973	205	45	392	86	597	131
1972	190	42	340	75	530	117
1971	183	40	388	85	571	126
1970	185	41	426	94	611	134
1969	203[2/]	45	427	94	630	139
1968	203[2/]	45	389	86	592	130
1967	188[2/]	45	407	90	595	131
1966	184[2/]	41	403	89	587	129
1965	165[2/]	40	367	81	532	117
1964	164[2/]	36	376	83	540	119
1963	159	35	344	76	503	111
1962	[3/]		314	69		
1961	[3/]		273	60		

[1/] Minnesota's production was not shown in U.S. Department of Commerce, Bureau of the Census, Current Industrial Report Series MA-24T. Therefore, this State's production was estimated by calculating its share of the production in the West North Central Division (U.S. Department of Commerce, Bureau of the Census, Manufacturers Series). The assumption was made that its production share equals its share of the value-added by manufacture in SIC 242, Sawmills and Planing Mills, within the same region, (i.e., about 22 percent).

[2/] Softwood production estimates for these years are below standard levels of consistency.

[3/] Suppressed data.

Table 32.--Residential construction in Michigan, Wisconsin, and Minnesota

Year	Construction permits[1/]	Single-family		Multi-family	
	Thousand	Percent[1/]	Thousand	Percent[2/]	Thousand
			MICHIGAN		
1983	21.2	0.61	12.9	0.38	8.1
1982	14.3	.53	7.6	.44	6.3
1981	19.1	.58	11.1	.40	7.6
1980	29.8	.56	16.7	.42	12.5
1979	49.3	.63	31.1	.36	17.7
1978	61.1	.67	40.9	.33	20.2
1977	58.7	.67	39.3	.33	19.4
1976	45.9	.67	30.8	.33	15.1
1975	37.0	.70	25.9	.29	10.7
1974	44.3	.63	27.9	.36	15.9
1973	71.3	.64	45.6	.45	32.1
1972	76.6	.52	39.8	.47	36.0
			WISCONSIN		
1983	16.1	0.61	9.8	0.38	6.1
1982	12.3	.53	6.5	.44	5.4
1981	14.2	.58	8.2	.40	5.7
1980	18.5	.56	10.4	.42	7.8
1979	26.6	.63	16.8	.36	9.6
1978	37.7	.67	25.3	.33	12.4
1977	41.3	.67	27.7	.33	13.6
1976	35.3	.67	23.7	.33	11.6
1975	26.0	.70	18.2	.29	7.5
1974	26.0	.63	16.4	.36	9.4
1973	34.2	.64	21.9	.45	15.4
1972	36.3	.52	18.9	.47	17.1
			MINNESOTA		
1983	24.9	0.61	15.2	0.38	9.5
1982	19.0	.53	10.1	.44	8.4
1981	17.4	.58	10.1	.40	7.0
1980	21.7	.56	12.2	.42	9.1
1979	29.4	.63	18.5	.36	10.6
1978	37.8	.67	25.3	.33	12.5
1977	38.3	.67	25.7	.33	12.6
1976	27.0	.67	18.1	.33	8.9
1975	19.2	.70	13.4	.29	5.6
1974	20.6	.63	13.0	.36	7.4
1973	23.3	.64	14.9	.45	10.5
1972	37.3	.52	19.4	.47	17.5

1/ U.S. Department of Commerce, International Trade Administration. Data for 1978-1983 is from survey of 16,000 permit-issuing places. Data for 1972-1977 is from survey of 14,000 permit-issuing places. Comparisons of the data are reasonable.

2/ Assumes that Michigan, Wisconsin, and Minnesota's ratios for single- and multi-family home construction are the same as those in the North Central region.

Table 33.--Lumber used in single-family home construction in Michigan, Wisconsin, Minnesota, and the Lake States

Year	Construction permits[1]	Size	Softwood	Hardwood	Consumption		
					Softwood	Hardwood	Total
	Thousand	Thousand square feet	Board feet per square foot[2]		Million board feet		
MICHIGAN							
1981	11.1	1.70	6.60	0.24	124.5	4.5	129.1
1977	39.3	1.72	6.72	.24	454.2	16.2	470.5
1973	45.6	1.69	7.00	.30	539.4	23.1	562.6
WISCONSIN							
1981	8.2	1.70	6.60	0.24	92.0	3.3	95.3
1977	27.7	1.72	6.72	.24	320.2	11.4	331.6
1973	21.9	1.69	7.00	.30	259.1	11.1	270.2
MINNESOTA							
1981	10.1	1.70	6.60	0.24	113.3	4.1	117.4
1977	25.7	1.72	6.72	.24	297.1	10.6	307.7
1973	14.9	1.69	7.00	.30	176.3	7.6	183.8
LAKE STATES							
1981	29.4	1.70	6.60	0.24	329.9	12.0	341.9
1977	92.7	1.72	6.72	.24	1,071.5	38.3	1,109.7
1973	82.4	1.69	7.00	.30	974.8	41.8	1,016.6

[1] U.S. Department of Commerce, International Trade Administration.
[2] Spelter and Phelps (1984).

Table 34.--Lumber used in multi-family home construction in Michigan, Wisconsin, Minnesota, and the Lake States

Year	Construction permits[1]	Size	Softwood	Hardwood	Consumption		
					Softwood	Hardwood	Total
	Thousand	Thousand square feet	Board feet per square foot[2]		Million board feet		
MICHIGAN							
1981	7.6	0.97	4.45	0.04	32.8	0.3	33.1
1977	19.4	.94	4.81	.07	87.7	1.3	89.0
1973	32.1	1.05	4.43	.08	149.3	2.7	152.0
WISCONSIN							
1981	5.7	0.97	4.45	0.04	24.6	0.2	24.8
1977	13.6	.94	4.81	.07	61.5	.9	62.4
1973	15.4	1.05	4.43	.08	71.6	1.3	72.9
MINNESOTA							
1981	7.0	0.97	4.45	0.04	30.2	0.3	30.5
1977	12.6	.94	4.81	.07	57.0	.8	57.8
1973	10.5	1.05	4.43	.08	48.8	.9	49.7
LAKE STATES							
1981	20.3	0.97	4.45	0.04	87.6	0.8	88.4
1977	45.6	.94	4.81	.07	206.2	3.0	209.2
1973	58.0	1.05	4.43	.08	269.8	4.9	274.7

[1] U.S. Department of Commerce, International Trade Administration.
[2] Spelter and Phelps (1984).

Table 35.--Lumber used in new mobile homes in Michigan, Wisconsin, Minnesota, and the Lake States

Year	Shipments[1/]	Size	Softwood	Hardwood	Consumption		
					Softwood	Hardwood	Total
	Thousand	Thousand square feet	Board feet per square foot[2/]		Million board feet		
MICHIGAN							
1981	4.3	1.05	2.75	0.10	12.4	0.5	12.9
1977	7.5	1.00	2.69	.10	20.2	.8	20.9
1973	22.3	.88	2.40	.10	47.1	2.0	49.1
WISCONSIN							
1981	3.1	1.05	2.75	0.10	9.0	0.3	9.3
1977	5.0	1.00	2.69	.10	13.5	.5	14.0
1973	10.0	.88	2.40	.10	21.1	.9	22.0
MINNESOTA							
1981	4.0	1.05	2.75	0.10	11.6	0.4	12.0
1977	5.0	1.00	2.69	.10	13.5	.5	14.0
1973	6.7	.88	2.40	.10	14.2	.6	14.7
LAKE STATES							
1981	11.4	1.05	2.75	0.10	32.9	1.2	34.1
1977	17.5	1.00	2.69	.10	47.1	1.8	48.8
1973	39.0	.88	2.40	.10	82.4	3.4	85.8

[1/] U.S. Department of Commerce, International Trade Administration. Mobile home shipments to Minnesota are estimated from shipments to the North Central region, assuming that the State's share is the same as its share of residential construction within the region.

[2/] Spelter and Phelps (1984).

Table 36.--Lumber used in residential alterations and repairs in Michigan, Wisconsin, Minnesota, and the Lake States

Year	Valuation[1]			Softwood 1977[2]	Consumption
	Nominal	CPI	1977		Softwood
	Million dollars		Million dollars	Board feet per dollar	Million board feet
MICHIGAN					
1983	160.9	0.612	98.5	0.21	20.7
1982	138.5	.628	87.0	.21	18.3
1981	171.5	.665	114.0	.21	23.9
1980	203.6	.736	149.8	.21	31.5
1979	209.3	.836	175.0	.20	35.0
1978	173.3	.929	161.0	.20	32.2
WISCONSIN					
1983	131.7	0.612	80.6	0.21	16.9
1982	125.9	.628	79.1	.21	16.6
1981	122.5	.665	81.5	.21	17.1
1980	122.1	.736	89.9	.21	18.9
1979	110.8	.836	92.6	.20	18.5
1978	108.3	.929	100.6	.20	20.1
MINNESOTA					
1983	190.2	0.612	116.4	0.21	24.4
1982	188.9	.628	118.6	.21	24.9
1981	159.3	.665	105.9	.21	22.2
1980	149.3	.736	109.9	.21	23.1
1979	123.1	.836	102.9	.20	20.6
1978	108.3	.929	100.6	.20	20.1
LAKE STATES					
1983	482.8	0.612	295.5	0.21	62.0
1982	453.3	.628	284.7	.21	59.8
1981	453.3	.665	301.4	.21	63.3
1980	475.0	.736	349.6	.21	73.4
1979	443.2	.836	370.5	.20	74.1
1978	389.9	.929	362.2	.20	72.4

[1] U.S. Department of Commerce, International Trade Administration. Based on valuation of residential alterations and repairs in the North Central Region. Assumes each State's share of the region's residential permits is the same as its share of the region's alterations and repairs.

[2] Spelter and Phelps (1984).

Table 37.--Lumber used in nonresidential building construction in Michigan, Wisconsin, Minnesota, and the Lake States

Year	Construction value[1]			1977[2]		Consumption		
	Nominal	CPI	1977	Softwood	Hardwood	Softwood	Hardwood	Total
	Million dollars		Million dollars	Board feet per dollar		Million board feet		
MICHIGAN								
1983	1,191	0.612	729	0.03	0.005	21.9	3.6	25.5
1982	1,092	.628	686	.03	.005	20.6	3.4	24.0
1981	1,439	.665	957	.03	.005	28.7	4.8	33.5
1980	1,631	.736	1,200	.03	.005	36.0	6.0	42.0
1979	1,619	.836	1,353	.03	.006	40.6	8.1	48.7
1978	1,391	.929	1,292	.03	.006	38.8	7.8	46.5
WISCONSIN								
1983	685	0.612	419	0.03	0.005	12.6	2.1	14.7
1982	634	.628	398	.03	.005	11.9	2.0	13.9
1981	777	.665	517	.03	.005	15.5	2.6	18.1
1980	805	.736	592	.03	.005	17.8	3.0	20.7
1979	883	.836	738	.03	.006	22.1	4.4	26.6
1978	741	.929	688	.03	.006	20.7	4.1	24.8
MINNESOTA								
1983	1,048	0.612	641	0.03	0.005	19.2	3.2	22.4
1982	1,006	.628	632	.03	.005	19.0	3.2	22.1
1981	962	.665	640	.03	.005	19.2	3.2	22.4
1980	1,029	.736	757	.03	.005	22.7	3.8	26.5
1979	1,171	.836	979	.03	.006	29.4	5.9	35.2
1978	1,026	.929	953	.03	.006	28.6	5.7	34.3
LAKE STATES								
1983	2,924	0.612	1,789	0.03	0.005	53.7	8.9	62.6
1982	2,732	.628	1,716	.03	.005	51.5	8.6	60.0
1981	3,178	.665	2,113	.03	.005	63.4	10.6	74.0
1980	3,465	.736	2,550	.03	.005	76.5	12.8	89.3
1979	3,673	.836	3,070	.03	.006	92.1	18.4	110.5
1978	3,158	.929	2,933	.03	.006	88.0	17.6	105.6

[1] Based on U.S. Department of Commerce, International Trade Administration Includes nonresidential alterations and repairs.

[2] Spelter and Phelps (1984).

Table 38.--Lumber used in pallet manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States

Year	U.S. consumption[1]		State(s) share[2]	State consumption		
	Softwood	Hardwood		Softwood	Hardwood	Total
	Million board feet		Percent	Million board feet		
			MICHIGAN			
1981	1,000	2,510	8.0	80.0	200.8	280.8
1977	970	2,290	8.6	83.4	196.9	280.4
1973	800	2,000	9.9	79.2	198.0	277.2
			WISCONSIN			
1981	1,000	2,510	6.0	60.0	150.6	210.6
1977	970	2,290	5.6	54.3	128.2	182.6
1973	800	2,000	4.3	34.4	86.0	120.4
			MINNESOTA			
1981	1,000	2,510	1.3	13.0	32.6	45.6
1977	970	2,290	1.3	12.6	29.8	42.4
1973	800	2,000	1.3	10.4	26.0	36.4
			LAKE STATES			
1981	1,000	2,510	15.3	153.0	384.0	537.0
1977	970	2,290	15.5	150.4	355.0	505.3
1973	800	2,000	15.5	124.0	310.0	434.0

[1] Spelter and Phelps (1984).
[2] U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes that the State's share of value-added in SIC 2448, wood pallets and skids, represents its share of the nation's total lumber consumption in pallet manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 39.--Lumber used in container and dunnage manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States

Year	U.S. consumption[1]		State(s) share[2]	State consumption		
	Softwood	Hardwood		Softwood	Hardwood	Total
	Million board feet		Percent	Million board feet		
			MICHIGAN			
1981	650	570	6.2	40.3	35.3	75.6
1977	650	590	6.4	41.6	37.8	79.4
1973	940	800	6.6	62.0	52.8	114.8
			WISCONSIN			
1981	650	2,510	2.9	18.9	72.8	91.6
1977	650	2,290	2.8	18.2	64.1	82.3
1973	940	2,000	2.7	25.4	54.0	79.4
			MINNESOTA			
1981	650	570	1.6	10.4	9.1	19.5
1977	650	590	1.6	10.4	9.4	19.8
1973	940	800	1.6	15.0	12.8	27.8
			LAKE STATES			
1981	650	570	10.7	69.6	117.3	186.8
1977	650	590	10.8	70.2	111.3	181.5
1973	940	800	10.9	102.5	119.6	222.1

[1] Spelter and Phelps (1984).
[2] U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes that the State's share of value-added in all U.S. manufacturing industries represents its share of the nation's total lumber consumption in container and dunnage manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 40.--Lumber used in furniture manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States

Year	U.S. consumption[1]		State(s) share[2]	State consumption		
	Softwood	Hardwood		Softwood	Hardwood	Total
	Million board feet		Percent	Million board feet		
			MICHIGAN			
1981	1,380	1,840	8.0	110.4	147.2	257.6
1977	1,280	1,870	7.5	96.0	140.3	236.3
1973	1,210	2,260	6.0	72.6	135.6	208.2
			WISCONSIN			
1981	1,380	1,840	2.5	34.5	46.0	80.5
1977	1,280	1,870	2.4	30.7	44.9	75.6
1973	1,210	2,260	2.1	25.4	47.5	72.9
			MINNESOTA			
1981	1,380	1,840	1.0	13.8	18.4	32.2
1977	1,280	1,870	1.0	12.8	18.7	31.5
1973	1,210	2,260	.9	10.9	20.3	31.2
			LAKE STATES			
1981	1,380	1,840	11.5	158.7	211.6	370.3
1977	1,280	1,870	10.9	139.5	203.8	343.3
1973	1,210	2,260	9.0	108.9	203.4	312.3

[1] Spelter and Phelps (1984).
[2] U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes that the State's share of value-added in SIC 25, furniture and fixtures, represents its share of the nation's total lumber consumption in furniture manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 41.--Lumber used in other manufacturing in Michigan, Wisconsin, Minnesota, and the Lake States

Year	U.S. consumption[1]		State(s) share[2]	State consumption		
	Softwood	Hardwood		Softwood	Hardwood	Total
	Million board feet		Percent	Million board feet		
			MICHIGAN			
1981	1,170	510	6.2	72.5	31.6	104.2
1977	1,090	500	6.4	69.8	32.0	101.8
1973	1,050	580	6.6	69.3	38.3	107.6
			WISCONSIN			
1981	1,170	510	2.9	33.9	14.8	48.7
1977	1,090	500	2.8	30.5	14.0	44.5
1973	1,050	580	2.7	28.4	15.7	44.0
			MINNESOTA			
1981	1,170	510	1.6	18.7	8.2	26.9
1977	1,090	500	1.6	17.4	8.0	25.4
1973	1,050	580	1.6	16.8	9.3	26.1
			LAKE STATES			
1981	1,170	510	10.7	125.2	54.6	179.8
1977	1,090	500	10.8	117.7	54.0	171.7
1973	1,050	580	10.9	114.5	63.2	177.7

[1] Spelter and Phelps (1984).
[2] U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes that the State's share of value-added in all U.S. manufacturing industries, represents its share of the nation's total lumber consumption in container and dunnage manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 42.--Saw log production in Michigan, Wisconsin, and Minnesota by state of destination[1/]

(All species, million board feet, international 1/4-inch)

Year	Destination[2/]									
	Michigan	Wisconsin	Minnesota	Indiana	Kentucky	Ohio	Iowa	Missouri	Other[2/]	Total
					MICHIGAN					
1980	357.5	29.2	0.0[3/]	5.6	0.3	0.0				392.6
1978	520.0	39.4	.0	3.9	.0	.0				563.3
1977	454.2	55.7	.0	4.0	.0	.1				514.0
1975	331.4	25.0	.0	2.8	.1	.0				359.3
1972	427.0	24.5	.0	2.9	.0	.0				454.4
1969	417.6	8.1	.0	.3	.0	.1				426.1
					WISCONSIN					
1981	0.8	490.0	0.0				0.0		0.^	490.8
1980	1.4	385.4	.2				.0		.3	387.3
1975	3.6	329.5	.0				.6		1.0	334.7
1973	1.5	382.8	.5				.9		.8	386.5
					MINNESOTA					
1980	0.0	3.0	225.2				2.5	0.0		230.7
1975	.0	3.6	152.4				.0	.1		156.1
1973	.0	7.0	170.3				.1	.2		177.5

1/ USDA Forest Service, Primary Forest Products Industry and Timber Use, (North Central Region series).

2/ Other states that receive Michigan, Wisconsin, and Minnesota exports include Indiana, Illinois, Kentucky, and other Central States.

3/ Less than 50 thousand board feet.

Table 43.--Saw log production in Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total
			MICHIGAN		
1980	13.1	33.6	73.4	272.6	392.7
1978	23.0	42.1	127.1	371.1	563.3
1977	37.7	53.8	98.4	324.1	514.0
1975	14.7	35.2	63.2	246.1	359.2
1972	12.5	46.8	64.0	331.1	454.4
1969	7.3	43.9	43.1	331.8	426.1
1965	6.0	32.9	35.7	312.9	387.5
			WISCONSIN		
1981	19.7	56.0	76.4	338.7	490.8
1980	16.6	50.6	57.2	262.9	387.3
1975	16.8	46.4	50.1	221.3	334.6
1973	11.3	32.3	74.3	268.6	386.5
1967	4.1	24.6	30.7	213.1	272.5
			MINNESOTA		
1980	50.3	28.5	80.8	71.1	230.7
1975	39.8	21.1	49.5	45.7	156.1
1973	25.8	29.4	60.7	61.6	177.5
1960	39.6	36.5	37.6	54.4	168.1

[1/] USDA Forest Service, Primary Forest Products Industry and Timber Use, North Central Region series.

Table 44.--Saw log receipts in Michigan, Wisconsin, and Minnesota by state of origin[1/]

(All species, million board feet, international 1/4-inch)

Year	Michigan	Wisconsin	Minnesota	Ohio	Iowa	Indiana	Total
			MICHIGAN				
			Origin				
1980	357.5	1.4	0.0[2/]	0.0		0.0	358.9
1978	520.0	4.4	.0	1.0		.0	525.4
1977	454.2	1.6	.0	1.3		.0	457.1
1972	427.0	1.9	.0	.0		.7	429.6
1969	417.6	.2	.0	.0		.4	418.2
			WISCONSIN				
1981	39.4	490.0	8.6		0.8		538.9[3/]
1980	29.2	385.4	3.0		5.0		422.6
1973	17.9	382.8	6.9		.7		408.3
			MINNESOTA				
1980	0.0	0.2	225.2		0.9		226.3
1973	.0	.4	170.3		1.6		172.2

[1/] USDA Forest Service, Primary Forest Products Industry and Timber Use, North Central Region series.

[2/] Less than 50 thousand board feet.

[3/] Wisconsin also receives some saw logs from Illinois and Canada.

Table 45.--Saw log receipts in Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total
			MICHIGAN		
1980	9.7	26.1	64.9	258.2	358.9
1978	15.6	34.2	108.6	366.9	525.3
1977	26.1	34.5	81.7	314.8	457.1
1972	11.3	44.2	49.5	324.6	429.6
1969	7.1	43.0	38.5	329.7	418.3
			WISCONSIN		
1981	23.4	65.7	88.7	361.0	538.9
1980	20.1	58.6	65.8	278.2	422.6
1973	14.7	36.4	82.2	275.0	408.3
1967	4.1	26.1	34.9	292.8	288.0
			MINNESOTA		
1980	50.0	28.2	80.9	67.2	226.3
1973	25.3	28.0	60.5	58.4	172.2

[1/] USDA Forest Service, Primary Forest Products Industry and Timber Use, North Central Region series.

Table 46.--Saw log imports into Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total
			MICHIGAN		
1980	0.0[2/]	0.0	0.6	0.8	1.4
1978	.0	.4	.4	4.6	5.4
1977	.0	.2	.5	2.2	2.9
1972	.3	.7	.1	1.5	2.6
1969	.0	.2	.0	.4	.6
			WISCONSIN		
1981	3.8	9.6	12.4	23.0	48.8
1980	3.6	7.9	9.4	16.4	37.2
1973	3.5	4.5	7.9	9.7	25.6
			MINNESOTA		
1980	0.0	0.0	0.2	0.9	1.1

[1/] USDA Forest Service, Primary Forest Products Industry and Timber Use, North Central Region series.

[2/] Less than 50 thousand board feet.

Table 47.--Saw log exports from Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Hard pine	Other softwoods	Aspen	Other hardwoods	Total
			MICHIGAN		
1980	3.3	7.6	9.1	15.1	35.1
1978	7.4	8.3	18.9	8.8	43.4
1977	11.6	19.5	17.2	11.5	59.8
1975	1.1	1.2	14.7	11.4	28.4
1972	1.6	3.2	14.3	8.4	27.5
1969	.1	1.2	4.7	2.4	8.4
			WISCONSIN		
1981	0.0[2/]	0.0	0.1	0.7	0.8
1980	.0	.0	.8	1.1	1.9
1975	.5	.8	.2	3.7	5.2
1973	.0	.5	.0	3.3	3.7
			MINNESOTA		
1980	0.3	0.3	0.1	4.8	5.5
1975	1.1	.5	.1	2.0	3.7
1973	.6	1.7	.2	4.8	7.3

[1/] USDA Forest Service, Primary Forest Products Industry and Timber Use, North Central Region series.

[2/] Less than 50 thousand board feet.

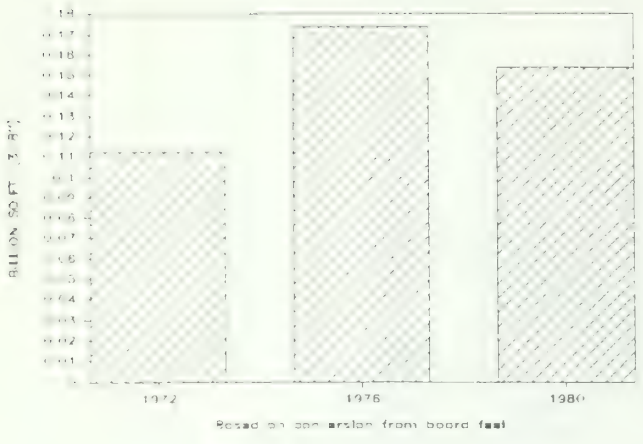


Figure 36.—*Hardwood veneer log receipts in the Lake States.*

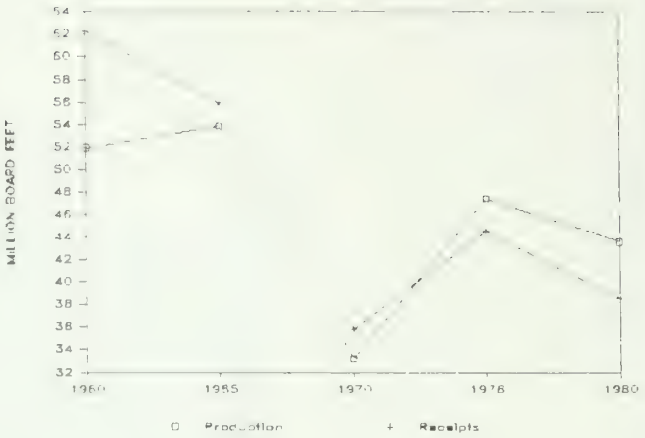


Figure 39.—*Veneer log production and receipts in the Lake States.*

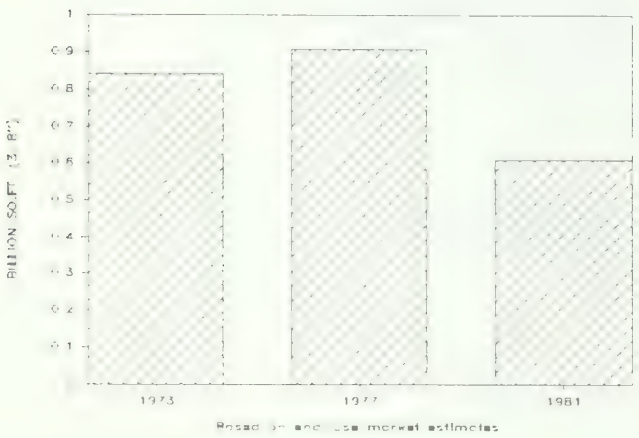


Figure 37.—*Plywood and veneer consumption in the Lake States.*

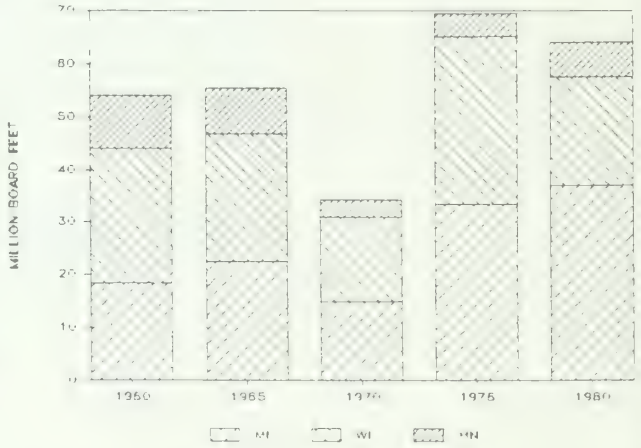


Figure 40.—*Veneer log production in the Lake States.*

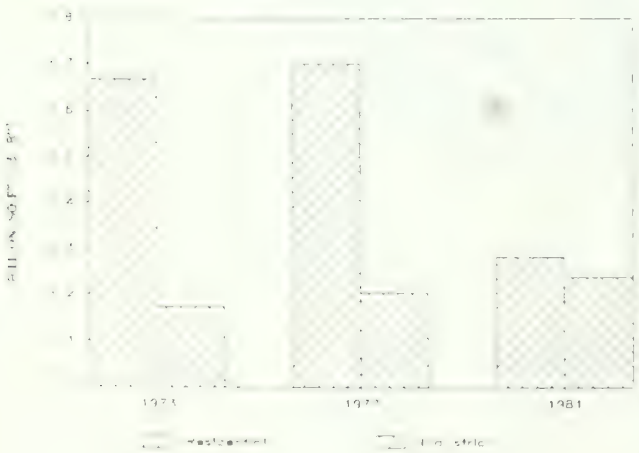


Figure 38.—*Lake States plywood and veneer consumption by end use.*

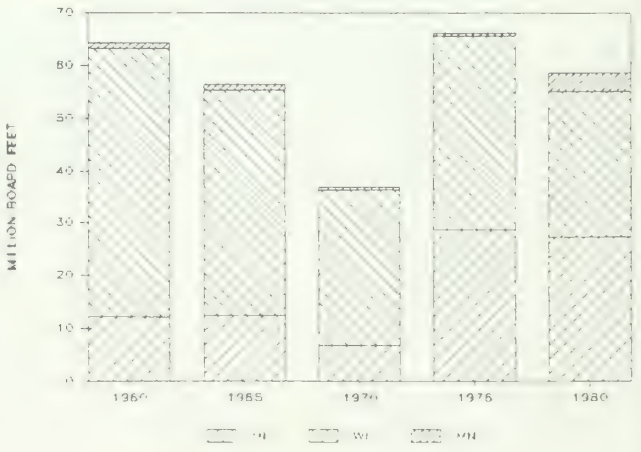


Figure 41.—*Veneer log receipts in the Lake States.*



Figure 42.—*Veneer log production in the Lake States by species groups.*



Figure 43.—*Veneer log receipts in the Lake States by species groups.*

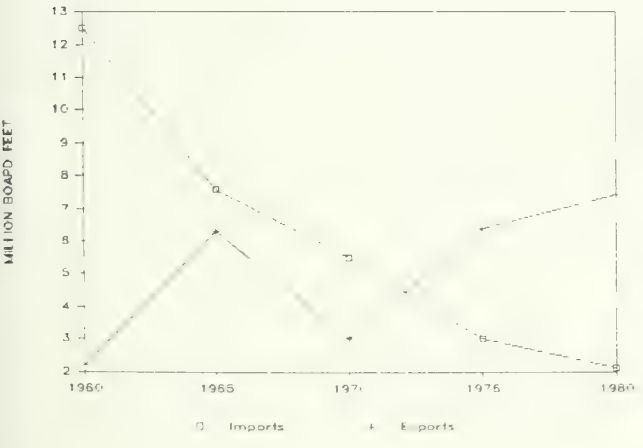


Figure 44.—*Lake States veneer log imports and exports.*

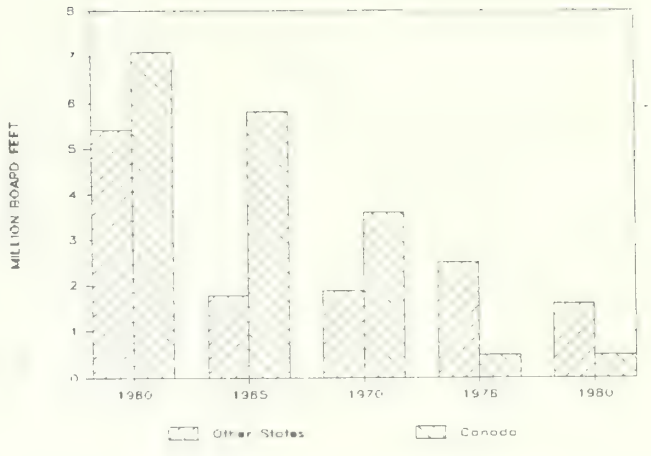


Figure 45.—*Veneer log imports to the Lake States from other states and Canada.*

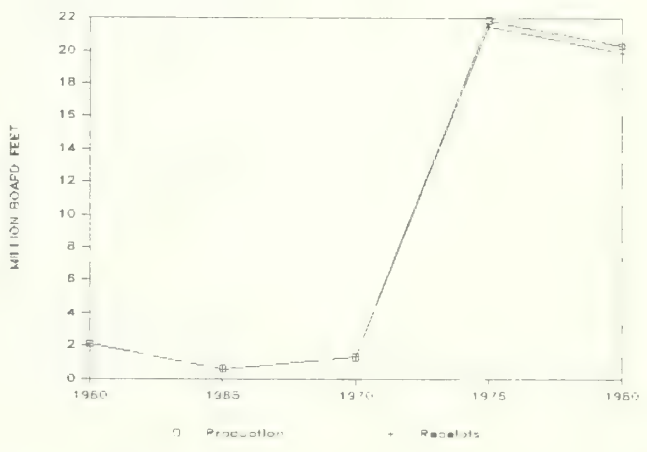


Figure 46.—*Production and receipts of aspen veneer logs in the Lake States.*

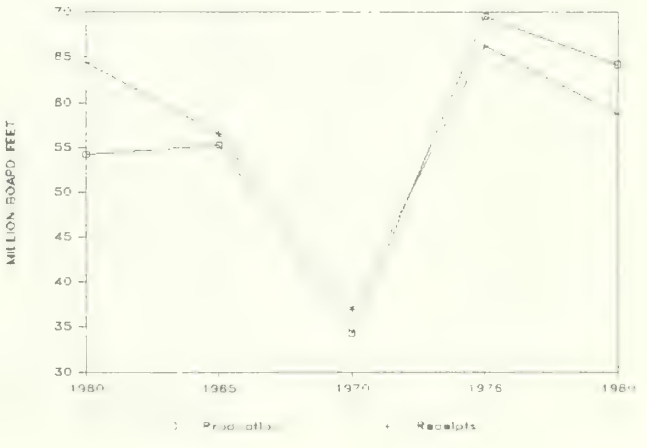


Figure 47.—*Production and receipts of other hardwood veneer logs in the Lake States.*

Table 48.--Hardwood veneer log receipts in the Lake States[1/]

(In million square feet, 3/8-inch)

Year	Aspen	Other	Total
1980	52.5	101.6	154.2
1976	56.8	117.5	174.2
1972	6.3	105.3	111.7
1970	3.4	94.5	97.9
1968	1.6	124.1	125.7
1966	1.8	144.1	146.0
1965	1.6	147.8	149.4
1963	4.0	135.2	139.2
1960	5.5	164.5	170.0

[1/] USDA Forest Service, Veneer Log Production and Receipts, North Central Region. Figures obtained by converting board feet to square feet using conversion factor 2,640 square feet (3/8-inch) per 1,000 board feet (Internationl 1/4-inch).

Table 49.--Plywood used in single-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	Construction permits[1/]	Square feet per home[2/]	Total
	Thousand		Million square feet
		LAKE STATES	
1981	34.5	5.84	201.5
1977	92.7	5.82	539.5
1973	82.4	5.67	467.2
		MICHIGAN	
1981	11.1	5.84	64.8
1977	39.3	5.82	228.7
1973	45.6	5.67	258.6
		WISCONSIN	
1981	8.2	5.84	47.9
1977	27.7	5.82	161.2
1973	21.9	5.67	124.2
		MINNESOTA	
1981	15.2	5.84	88.8
1977	25.7	5.82	149.6
1973	14.9	5.67	84.5

[1/] U.S. Department of Commerce, International Trade Administration.

[2/] Based on interpolations, USDA Forest Service (1982).

Table 50.--Plywood used in multi-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	Construction permits[1]	Square feet per home[2]	Total
	Thousand		Million square feet
LAKE STATES			
1981	20.3	2.92	59.3
1977	45.6	2.93	133.6
1973	58.0	2.50	145.0
MICHIGAN			
1981	7.6	2.92	22.2
1977	19.4	2.93	56.8
1973	32.1	2.50	80.3
WISCONSIN			
1981	5.7	2.92	16.6
1977	13.6	2.93	39.8
1973	15.4	2.50	38.5
MINNESOTA			
1981	7.0	2.92	20.4
1977	12.6	2.93	36.9
1973	10.5	2.50	26.3

[1] U.S. Department of Commerce, International Trade Administration.

[2] Based on interpolations, USDA Forest Service (1982).

Table 51.--Plywood used in new mobile homes in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	Shipments[1]	Square feet per home[2]	Total
	Thousand		Million square feet
LAKE STATES			
1981	11.4	1.83	20.9
1977	17.5	1.65	28.9
1973	39.0	1.45	56.6
MICHIGAN			
1981	4.3	1.83	7.9
1977	7.5	1.65	12.4
1973	22.3	1.45	32.3
WISCONSIN			
1981	3.1	1.83	5.7
1977	5.0	1.65	8.3
1973	10.0	1.45	14.5
MINNESOTA			
1981	4.0	1.83	7.3
1977	5.0	1.65	8.3
1973	6.7	1.45	9.7

[1] U.S. Department of Commerce, International Trade Administration. Mobile home shipments to the State are estimated from shipments to the North Central region, assuming the State's share is the same as its share of residential construction within the region.

[2] Based on interpolations, USDA Forest Service (1982).

Table 52.--Plywood used in residential alterations and repairs in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	Valuation[1/]			1972[2/]	Consumption
	Nominal	CPI	1972		
	Million dollars		Million dollars	Square feet per dollar	Million square feet
LAKE STATES					
1983	482.8	0.422	203.7	0.162	33.0
1982	453.3	.433	196.3	.163	32.0
1981	453.3	.459	208.1	.163	33.9
1980	475.0	.508	241.3	.164	39.6
1979	443.2	.577	255.7	.164	41.9
1978	389.9	.641	249.9	.165	41.2
MICHIGAN					
1983	160.9	0.422	67.9	0.162	11.0
1982	138.5	.433	60.0	.163	9.8
1981	171.5	.459	78.7	.163	12.8
1980	203.6	.508	103.4	.164	17.0
1979	209.3	.577	120.8	.164	19.8
1978	173.3	.641	111.1	.165	18.3
WISCONSIN					
1983	131.7	0.422	55.6	0.162	9.0
1982	125.9	.433	54.5	.163	8.9
1981	122.5	.459	56.2	.163	9.2
1980	122.1	.508	62.0	.164	10.2
1979	110.8	.577	63.9	.164	10.5
1978	108.3	.641	69.4	.165	11.5
MINNESOTA					
1983	190.2	0.422	80.3	0.162	13.0
1982	188.9	.433	81.8	.163	13.3
1981	159.3	.459	73.1	.163	11.9
1980	149.3	.508	75.8	.164	12.4
1979	123.1	.577	71.0	.164	11.6
1978	108.3	.641	69.4	.165	11.5

[1/] U.S. Department of Commerce, International Trade Administration. Based on valuation of residential alterations and repairs in the North Central Region. Assumes each State's share of the region's residential permits is the same as its share of the region's alterations and repairs.

[2/] Based on interpolations, USDA Forest Service (1982).

Table 53.--Plywood used in nonresidential building construction in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	Construction value[1]				Consumption
	Nominal	CPI	1972	1972[2]	
	Million dollars		Million dollars	Square feet per dollar	Million square feet
			LAKE STATES		
1983	2,924	0.422	1,233.9	0.039	48.1
1982	2,732	.433	1,183.0	.039	46.1
1981	3,180	.459	1,459.6	.038	55.5
1980	3,465	.508	1,760.2	.038	66.9
1979	3,673	.577	2,119.3	.037	78.4
1978	3,158	.641	2,024.3	.037	74.9
			MICHIGAN		
1983	1,191	0.422	502.6	0.039	19.6
1982	1,092	.433	472.8	.039	18.4
1981	1,439	.459	660.5	.038	25.1
1980	1,631	.508	828.5	.038	31.5
1979	1,619	.577	934.2	.037	34.6
1978	1,391	.641	891.6	.037	33.0
			WISCONSIN		
1983	685	0.422	289.1	0.039	11.3
1982	634	.433	274.5	.039	10.7
1981	779	.459	357.6	.038	13.6
1980	805	.508	408.9	.038	15.5
1979	883	.577	509.5	.037	18.9
1978	741	.641	475.0	.037	17.6
			MINNESOTA		
1983	1,048	0.422	442.3	0.039	17.2
1982	1,006	.433	435.6	.039	17.0
1981	962	.459	441.6	.038	16.8
1980	1,029	.508	522.7	.038	19.9
1979	1,171	.577	675.7	.037	25.0
1978	1,026	.641	657.7	.037	24.3

[1] U.S. Department of Commerce, International Trade Administration.

[2] Based on interpolations, USDA Forest Service (1982).

Table 54.--Plywood and veneer used in furniture manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	U.S. consumption[1/]	State share[2/]	State consumption
	Million square feet	Percent	Million square feet
		LAKE STATES	
1981	1,017	11.5	117.0
1977	939	10.9	102.4
1973	993	9.0	89.4
		MICHIGAN	
1981	1,017	8.0	81.4
1977	939	7.5	70.4
1973	993	6.0	59.6
		WISCONSIN	
1981	1,017	2.5	25.4
1977	939	2.4	22.5
1973	993	2.1	20.9
		MINNESOTA	
1981	1,017	1.0	10.2
1977	939	1.0	9.4
1973	993	.9	8.9

[1/] Based on interpolations, USDA Forest Service (1982).

[2/] U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes the State's share of value-added in SIC 25, Furniture and Fixtures, represents its share of the nation's total plywood and veneer consumption in furniture manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 55.--Plywood and veneer used in pallet manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	U.S. consumption[1/]	State share[2/]	State consumption
	Million square feet	Percent	Million square feet
		LAKE STATES	
1981	557	15.3	85.2
1977	431	15.5	66.8
1973	270	15.5	41.9
		MICHIGAN	
1981	557	8.0	44.6
1977	431	8.6	37.1
1973	270	9.9	26.7
		WISCONSIN	
1981	557	6.0	33.4
1977	431	5.6	24.1
1973	270	4.3	11.6
		MINNESOTA	
1981	557	1.3	7.2
1977	431	1.3	5.6
1973	270	1.3	3.5

[1/] Based on interpolations, USDA Forest Service (1982).

[2/] U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes the State's share of SIC 2448, Wood pallets and skids, represents its share of the nation's total plywood and veneer consumption in pallet manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 56.--Plywood and veneer used in container and dunnage manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota

(In 3/8-inch basis)

Year	U.S. consumption[1/]	State share[2/]	State consumption
	Million square feet	Percent	Million square feet
		LAKE STATES	
1981	323	10.7	34.6
1977	335	10.8	36.2
1973	374	10.9	40.8
		MICHIGAN	
1981	323	6.2	20.0
1977	335	6.4	21.4
1973	374	6.6	24.7
		WISCONSIN	
1981	323	2.9	9.4
1977	335	2.8	9.4
1973	374	2.7	10.1
		MINNESOTA	
1981	323	1.6	5.2
1977	335	1.6	5.4
1973	374	1.6	6.0

1/ Based on interpolations, USDA Forest Service (1982).

2/ U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes that the State's share of value-added in all U.S. manufacturing industries represents its share of the nation's total plywood and veneer consumption in container and dunnage manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 57.--Veneer log production in the Lake States[1/]

(All species, MMBF, international 1/4-inch)

Year	Michigan	Wisconsin	Minnesota	Total
1981		27.3		
1980	36.8	20.9	6.5	64.2
1978	35.2			
1977	42.8			
1976	33.4	31.7	4.5	69.6
1975	26.0	31.7	3.2	60.9
1973		32.2	5.2	
1972	18.6	19.5	4.2	42.3
1970	15.0	15.8	3.5	34.3
1969	19.2			
1968	19.3	21.1	5.2	45.6
1966	21.9	22.9	6.0	50.8
1965	22.4	24.4	8.5	55.3
1963	15.3	25.2	9.9	50.4
1960	18.5	25.5	10.2	54.2

1/ USDA Forest Service, veneer log production and receipts, North Central Region.

Table 58.--Veneer log receipts in the Lake States[1/]

(All species, MMBF, international 1/4-inch)

Year	Michigan	Wisconsin	Minnesota	Total
1981		34.5		
1980	27.3	27.9	3.5	58.7
1978	39.2			
1977	30.8			
1976	28.7	37.0	.6	66.3
1973		37.8		
1972	5.4	36.6	.5	42.5
1970	6.7	29.8	.4	36.9
1969	15.1			
1968	9.6	37.6	.5	47.7
1966	13.0	42.2	.5	55.7
1965	12.4	43.0	1.1	56.5
1963	7.6	41.8	3.2	52.6
1962		37.6		
1960	12.1	51.3	1.1	64.5

1/ USDA Forest Service, veneer log production and receipts, North Central Region.

Table 59.--Veneer log imports and exports in the Lake States[1/]

(In million board feet, international 1/4-inch)

Year	Imports			Exports
	Other States	Canada	Total	Outside region
1980	1.6	0.5	2.1	7.4
1976	2.5	.5	3.0	6.4
1975				2.0
1972	1.6	3.1	4.7	4.6
1970	1.9	3.6	5.5	3.0
1968	3.0	4.9	7.9	5.9
1966	2.8	7.0	9.8	5.0
1965	1.8	5.8	7.6	6.3
1963	1.9	5.8	7.7	5.6
1962	2.8	4.8	7.6	
1960	5.4	7.1	12.5	2.2

1/ USDA Forest Service, veneer log production and receipts, North Central Region.

Table 60.--Veneer log production in Michigan, Wisconsin, and Minnesota by state of destination[1/]

(All species, million board feet, international 1/4-inch)

Year	Destination								Total
	Michigan	Wisconsin	Minnesota[2/]	Indiana	Ohio	Kentucky	Other[3/] States	Canada	
MICHIGAN									
1980	22.1	9.0	0.0[4/]				5.6[5/]		36.8
1978	22.6	8.7	.0	1.5	0.3	0.1	1.2	0.8	35.2
1977	30.4	8.5	.0	2.3	.3	.5	.0	.8	42.8
1976	18.5	10.3	.0				4.6[5/]		33.4
1975	15.6	9.0	.0	.7	.2	.2	.0	.3	26.0
1972	4.6	10.9	.0	1.5	.7	.4	.0	.5	18.6
1970	5.4	7.3	.0				2.3[5/]		15.0
1969	12.7	4.5	.0	1.1	.2	.3	.0	.4[6/]	19.2
1968	8.4	8.0	.0				3.0[5/]		19.3
1966	10.7	8.3	.0				3.0[5/]		21.9
1965	10.3	8.0	.0				4.0[5/]		22.4
1963	5.3	5.9	.0				4.1[5/]		15.3
1960	8.6	8.7	.0				1.2[5/]		18.5
WISCONSIN									
1981	12.4	14.2	0.0				0.6		27.3
1980	5.2	14.3	.0[2/]				1.3		20.9
1976	9.8	20.8	.0				1.1		31.7
1975	10.9	20.4	.1				.3		31.7
1973	11.4	19.6	.0				1.2		32.2
1972	.1	18.2	.0				1.2		19.5
1970	.1	14.1	.0				.6		15.8
1968	.3	18.9	.0				1.9		21.1
1966	.6	20.5	.0				1.8		22.9
1965	.8	22.5	.0				1.1		24.4
1963	.5	23.8	.0				.9		25.2
1960	.5	24.2	.0				.8		25.5
MINNESOTA									
1980	2.5	3.5[2/]	0.0				0.5		6.5
1976	3.0	.4	.4				.7		4.5
1975	2.1	.4	.4				.3		3.2
1973	4.1	.4	.5				.2		5.2
1972	3.5	.4	.0				.3		4.2
1970	3.0	.3	.1				.1		3.5
1968	3.5	.5	.2				1.0		5.2
1966	5.2	.5	.1				.2		6.0
1965	6.1	1.1	.1				1.2		8.5
1963	6.1	3.0	.2				.6		9.9
1960	8.4	1.1	.5				.2		10.2

1/ USDA Forest Service, veneer log production and receipts, North Central Region.

2/ Minnesota and Wisconsin veneer log receipts were combined in 1980 survey. The study assumes that most of these receipts were within Wisconsin.

3/ Other states that receive Wisconsin and Minnesota exports include Indiana, Iowa, Kentucky and Missouri. Canada and other countries also receive some veneer log exports from Wisconsin and Minnesota.

4/ Less than 50 thousand board feet.

5/ Includes veneer logs shipped to states outside the Lake States and to Canada.

6/ Includes veneer logs shipped to Canada and other countries.

Table 61.--Veneer log production in the Lake States, Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Pine	Other softwoods	Aspen	Other hardwoods	Total
			LAKE STATES		
1980	0.3	0.0[2/]	20.3	43.6	64.2
1976	.4	.0	21.9	47.4	69.7
1975	.0	.0	24.2	36.7	60.9
1972	.0	.0	2.6	39.5	42.1
1970	.0	.0	1.3	33.2	34.5
1968	.0	.0	.6	45.0	45.6
1966	.1	.0	.7	50.1	50.9
1965	.0	.0	.6	53.8	54.4
1963	.0	.0	1.5	49.0	50.5
1960	.0	.0	2.1	51.9	54.0
			MICHIGAN		
1980	0.1	0.0	11.0	25.7	36.8
1978	.0	.0	16.0	19.0	35.0
1977	.0	.0	22.2	20.5	42.7
1976	.1	.0	11.0	22.3	33.4
1975	.0	.0	12.7	13.4	26.1
1972	.0	.0	.3	18.2	18.5
1970	.0	.0	.1	15.0	15.1
1969	.0	.0	4.0	15.2	19.2
1968	.0	.0	.2	19.1	19.3
1966	.0	.0	.3	21.6	21.9
1965	.0	.0	.4	22.0	22.4
1963	.0	.0	.3	15.0	15.3
1960	.0	.0	.2	18.3	18.5
			WISCONSIN		
1981	0.0	0.0	13.0	14.2	27.2
1980	.2	.0	5.8	14.9	20.9
1976	.3	.0	10.1	21.3	31.7
1975	.0	.0	11.1	20.5	31.6
1973	.0	.0	11.5	20.6	32.1
1972	.0	.0	2.1	17.3	19.4
1970	.0	.0	1.2	14.7	15.9
1968	.0	.0	.4	20.7	21.1
1966	.1	.0	.4	22.4	22.9
1965	.0	.0	.2	24.2	24.4
1963	.0	.0	.2	25.0	25.2
1960	.0	.0	1.3	24.1	25.4
			MINNESOTA		
1980	0.0	0.0	3.5	3.0	6.5
1976	.0	.0	.8	3.8	4.6
1975	.0	.0	.4	2.8	3.2
1973	.0	.0	.5	4.6	5.1
1972	.0	.0	.2	4.0	4.2
1970	.0	.0	.0	3.5	3.5
1968	.0	.0	.0	5.2	5.2
1966	.0	.0	.0	6.1	6.1
1965	.0	.0	.0	7.6	7.6
1963	.0	.0	1.0	9.0	10.0
1960	.0	.0	.6	9.5	10.1

[1/] USDA Forest Service, veneer log production and receipts, North Central Region.

[2/] Less than 50 thusand board feet.

Table 62.--Veneer log receipts in Michigan, Wisconsin, and Minnesota by state of origin[1/]

(All species, million board feet, international 1/4-inch)

Year	Origin					
	Michigan	Wisconsin	Minnesota	Other States[2/]	Canada	Total
			MICHIGAN			
1980	22.1	5.2	0.0[3/]	0.0	0.0	27.3
1978	22.6	15.0	1.0	.5	.1	39.2
1977	30.4	.0	.0	.4	.0	30.8
1976	18.5	9.8	.4	.0	.0	28.7
1972	4.6	.1	.0	.0	.7	5.4
1970	5.4	.1	.1	.2	.9	6.7
1969	12.7	1.5	.3	.1	.5	15.1
1968	8.4	.3	.2	.3	.4	9.6
1966	10.7	.6	.1	.2	1.4	13.0
1965	10.3	.8	.1	.2	1.0	12.4
1963	5.3	.5	.2	.2	1.4	7.6
1960	8.6	.5	.5	.2	2.3	12.1
			WISCONSIN			
1981	14.1	14.2	2.5	3.0	0.7	34.5
1980	9.0	14.3[4/]	2.5	1.6	.5	27.9
1976	10.3	20.8	3.0	2.4	.5	37.0
1973	10.9	19.6	4.1	2.0	1.2	37.8
1972	10.9	18.2	3.5	1.6	2.4	36.6
1970	7.3	15.1	3.0	1.7	2.7	29.8
1968	8.0	18.9	3.5	2.7	4.5	37.6
1966	8.3	20.5	5.2	2.6	5.6	42.2
1965	8.0	22.5	6.1	1.6	4.8	43.0
1963	5.9	23.8	6.1	1.7	4.3	41.8
1962	5.0	18.8	6.2	2.8	4.8	37.6
1960	8.7	24.2	8.4	5.2	4.8	51.3
			MINNESOTA			
1980	0.0	0.0	3.5[4/]	0.0	0.0	3.5
1976	.0	.0	.4	.1	.0	.6
1972	.0	.0	.4	.0	.0	.5
1970	.0	.0	.3	.0	.0	.4
1968	.0	.0	.5	.0	.0	.5
1966	.0	.0	.5	.0	.0	.5
1965	.0	.0	1.1	.0	.0	1.1
1963	.0	.0	3.0	.0	.1	3.1
1960	.0	.0	1.1	.0	.0	1.1

[1/] USDA Forest Service, veneer log production and receipts, North Central Region.

[2/] Includes shipments from Iowa, Illinois, Indiana, Kentucky, Ohio, and Pennsylvania and small amounts from other Central and Western States.

[3/] Less than 50 thousand board feet.

[4/] Minnesota and Wisconsin veneer log receipts were combined in 1980 survey. The study assumes that most of these receipts were within Wisconsin.

Table 63.--Veneer log receipts in the Lake States, Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Pine	Other softwoods	Aspen	Other hardwoods	Total
			LAKE STATES		
1980	0.2	0.0[2/]	19.9	38.5	58.6
1976	.4	.0	21.5	44.5	66.4
1972	.0	.0	2.4	39.9	42.3
1970	.0	.0	1.3	35.8	37.1
1968	.0	.0	.6	47.0	47.6
1966	.1	.0	.7	54.6	55.4
1965	.0	.0	.6	56.0	56.6
1963	.0	.0	1.5	51.2	52.7
1960	.0	.0	2.1	62.3	64.4
			MICHIGAN		
1980	0.0	0.0	15.7	11.5	27.2
1978	.0	.0	31.7	7.4	39.1
1977	.0	.0	22.2	8.7	30.9
1976	.1	.0	21.0	7.7	28.8
1972	.0	.0	.2	5.1	5.3
1970	.0	.0	.1	6.7	6.8
1969	.0	.0	5.1	10.0	15.1
1968	.0	.0	.2	9.4	9.6
1966	.0	.0	.2	12.6	12.8
1965	.0	.0	.3	12.1	12.4
1963	.0	.0	.2	7.4	7.6
1960	.0	.0	.0	12.1	12.1
			WISCONSIN		
1981	0.2[3/]	0.0	0.6	33.8	34.6
1980	.2	.0	.7	27.0	27.9
1976	.3	.0	.5	36.2	37.0
1973	.0	.0	.4	37.3	37.7
1972	.0	.0	2.2	34.3	36.5
1970	.0	.0	1.2	28.7	29.9
1968	.0	.0	.4	37.1	37.5
1966	.1	.0	.5	41.5	42.1
1965	.0	.0	.3	42.8	43.1
1963	.0	.0	.3	41.6	41.9
1960	.0	.0	2.1	49.2	51.3
			MINNESOTA		
1980	0.0[3/]	0.0	3.5	0.0	3.5
1976	.0	.0	.0	.6	.6
1973	.0	.0	.1	.4	.5
1972	.0	.0	.0	.5	.5
1970	.0	.0	.0	.4	.4
1968	.0	.0	.0	.5	.5
1966	.0	.0	.0	.5	.5
1965	.0	.0	.0	1.1	1.1
1963	.0	.0	1.0	2.2	3.2
1960	.0	.0	.0	1.0	1.1

[1/] USDA Forest Service, veneer log production and receipts, North Central Region.

[2/] Less than 50 thousand board feet.

[3/] Minnesota and Wisconsin veneer log receipts were combined in 1980 survey. The study assumes that most of these receipts were within Wisconsin.

Table 64.--Veneer log imports into Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, International 1/4-inch rule)

Year	Pine	Other softwoods	Aspen	Other hardwoods	Total
			MICHIGAN		
1980	0.0[2/]	0.0	5.2	0.0	5.2
1978	.0	.0	16.0	.6	16.6
1977	.0	.0	.0	.5	.5
1976	.1	.0	10.0	.2	10.3
1972	.0	.0	.0	.8	.8
1970	.0	.0	.0	1.3	1.3
1969	.0	.0	1.1	1.2	2.3
1968	.0	.0	.0	1.2	1.2
1966	.0	.0	.0	2.1	2.1
1965	.0	.0	.0	2.1	2.1
1963	.0	.0	.0	2.3	2.3
1960	.0	.0	.0	3.4	3.4
			WISCONSIN		
1981	0.1	0.0	0.0	20.2	20.3
1980	.1[3/]	.0	.2	13.4	13.5
1976	.1	.0	.0	16.1	16.2
1973	.0	.0	.2	17.9	18.1
1972	.0	.0	.1	18.3	18.4
1970	.0	.0	.0	14.7	14.7
1968	.0	.0	.0	18.7	18.7
1966	.0	.0	.1	21.6	21.7
1965	.0	.0	.0	20.5	20.5
1963	.0	.0	.1	18.0	18.1
1960	.0	.0	.7	26.3	27.0
			MINNESOTA		
1980	0.0[3/]	0.0	0.0	0.0	0.0
1976	.0	.0	.0	.2	.2
1972	.0	.0	.0	.1	.1
1970	.0	.0	.0	.1	.1
1968	.0	.0	.0	.0	.0
1966	.0	.0	.0	.0	.0
1965	.0	.0	.0	.0	.0
1963	.0	.0	.0	.1	.1
1960	.0	.0	.0	.0	.0

[1/] USDA Forest Service, veneer log production and receipts, North Central Region.

[2/] Less than 50 thousand board feet.

[3/] Minnesota and Wisconsin veneer log receipts were combined in 1980 survey. The study assumes that most of these receipts were within Wisconsin.

Table 65.--Veneer log exports from Michigan, Wisconsin, and Minnesota by species group[1/]

(In million board feet, international 1/4-inch)

Year	Pine	Other softwoods	Aspen	Other hardwoods	Total
			MICHIGAN		
1980	0.1	0.0[2/]	0.5	14.2	14.8
1978	.0	.0	.2	12.2	12.4
1977	.0	.0	.0	12.3	12.3
1976	.1	.0	.0	14.7	14.8
1975	.0	.0	.0	10.5	10.5
1972	.0	.0	.0	13.9	13.9
1970	.0	.0	.0	9.6	9.6
1969	.0	.0	.0	6.5	6.5
1968	.0	.0	.0	11.0	11.0
1966	.0	.0	.1	11.2	11.3
1965	.0	.0	.0	12.0	12.0
1963	.0	.0	.1	10.0	10.1
1960	.0	.0	.2	9.9	10.1
			WISCONSIN		
1981	0.0	0.0	12.4	0.6	13.0
1980	.0	.0	5.2[3/]	1.3	6.5
1976	.1	.0	9.6	1.2	10.9
1975	.0	.0	10.9	.4	11.3
1973	.0	.0	11.3	1.3	12.6
1972	.0	.0	.0	1.3	1.3
1970	.0	.0	.0	.7	.7
1968	.0	.0	.0	2.2	2.2
1966	.0	.0	.0	2.4	2.4
1965	.0	.0	.0	1.9	1.9
1963	.0	.0	.0	1.4	1.4
1960	.0	.0	.0	1.2	1.2
			MINNESOTA		
1980	0.0[3/]	0.0	0.0	3.0	3.0
1976	.0	.0	.8	3.4	4.2
1975	.0	.0	.4	2.4	2.8
1973	.0	.0	.4	4.3	4.7
1972	.0	.0	.2	3.6	3.8
1970	.0	.0	.0	3.1	3.1
1968	.0	.0	.0	4.7	4.7
1966	.0	.0	.0	5.6	5.6
1965	.0	.0	.0	6.5	6.5
1963	.0	.0	.0	6.9	6.9
1960	.0	.0	.6	8.5	9.1

[1/] USDA Forest Service, veneer log production and receipts, North Central Region.

[2/] Less than 50 thousand board feet.

[3/] Minnesota and Wisconsin veneer log receipts were combined in 1980 survey. The study assumes that most of these receipts were within Wisconsin.

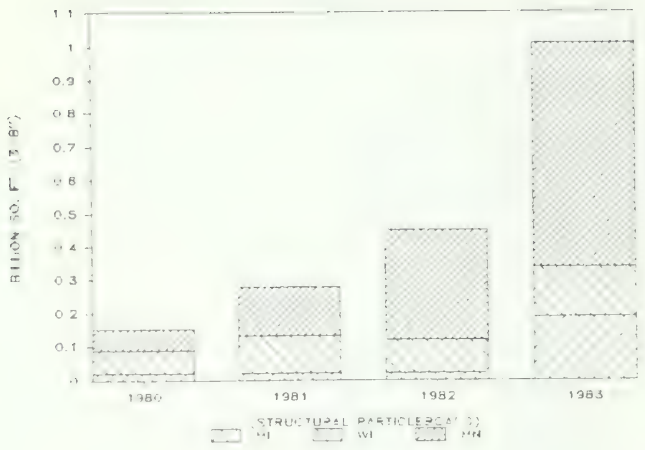


Figure 48.—*Structural panel production in the Lake States.*

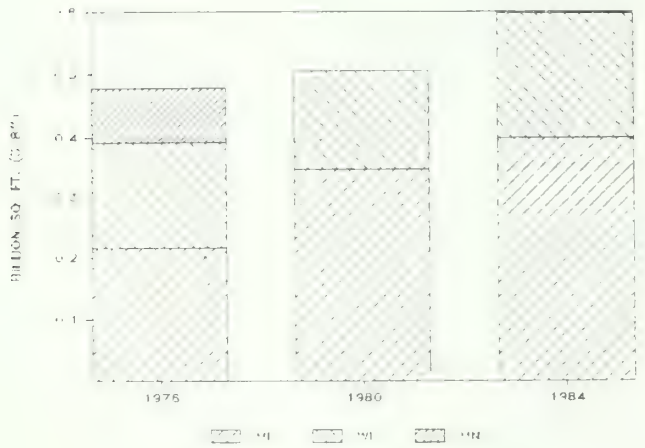


Figure 49.—*Particleboard productive-capacity in the Lake States.*

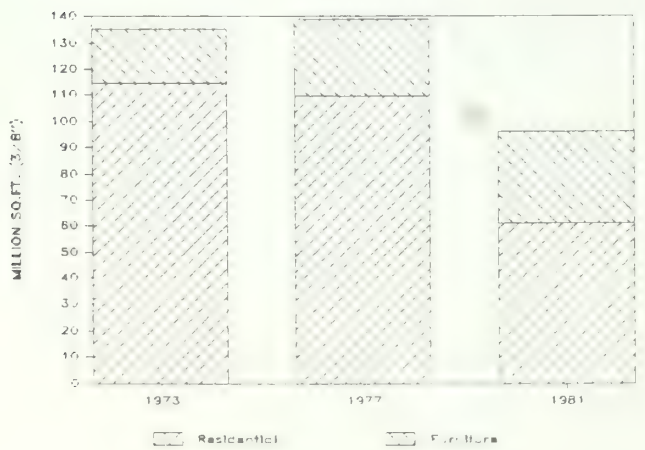


Figure 50.—*Lake States particleboard consumption by end use.*

Table 66.--Structural panel production in the Lake States[1/]

(In million square feet, 3/8-inch)

Year	Michigan	Minnesota	Wisconsin	Total
1983	185(2)[2/]	670(4)	151(1)	1,006
1982	21(2)	328(3)	99(1)	448
1981	19(1)	148(3)	111(1)	278
1980	20(1)	65(1)	70(1)	155

[1/] Anderson 1984. By definition, structural panel includes softwood plywood, waferboard, oriented strand board and composite plywood. Waferboard and OSB comprise most of the production in the Lake States and are referred to as structural particleboard throughout the study.

[2/] Number in parentheses shows number of mills.

Table 67.--Particleboard productive-capacity in the Lake States[1/]

(In million square feet, 3/4-inch)[2/]

Year	Michigan	Minnesota	Wisconsin	Total
1984	200(1)[3/]	--	99(2)	299
1981	180(1)	--	91(2)	271
1980	172(1)	--	81(2)	253
1976	108(1)	45(2)	86(2)	239

[1/] National Particleboard Association. Lake States mills produce "platenboard" or "mat-formed" particleboard which is used primarily in industrial markets.

[2/] Double production data to obtain 3/8-inch basis for comparison.

[3/] Number in parentheses shows number of mills.

Table 68.--Particleboard used in single-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota[1/]

(In 3/4-inch basis)

Year	Construction permits[2/]	Square feet per home[3/]	Total
	Thousand		Million square feet
LAKE STATES			
1981	34.5	0.52	17.9
1977	92.7	.38	34.9
1973	82.4	.30	24.6
MICHIGAN			
1981	11.1	0.52	5.8
1977	39.3	.38	14.8
1973	45.6	.30	13.6
WISCONSIN			
1981	8.2	0.52	4.3
1977	27.7	.38	10.4
1973	21.9	.30	6.5
MINNESOTA			
1981	15.2	0.52	7.9
1977	25.7	.38	9.7
1973	14.9	.30	4.4

1/ By USDA Forest Service definition, particleboard includes waferboard, oriented-strand board, composite board, and medium-density fiberboard.

2/ U.S. Department of Commerce, International Trade Administration.

3/ Based on interpolations, USDA Forest Service (1982).

Table 69.--Particleboard used in multi-family home construction in the Lake States, Michigan, Wisconsin, and Minnesota[1/]

(In 3/4-inch basis)

Year	Construction permits[2/]	Square feet per home[3/]	Total
	Thousand		Million square feet
LAKE STATES			
1981	20.3	0.16	3.1
1977	45.6	.11	4.9
1973	58.0	.09	4.9
MICHIGAN			
1981	7.6	0.16	1.2
1977	19.4	.11	2.1
1973	32.1	.09	2.7
WISCONSIN			
1981	5.7	0.16	0.9
1977	13.6	.11	1.5
1973	15.4	.09	1.3
MINNESOTA			
1981	7.0	0.16	1.1
1977	12.6	.11	1.3
1973	10.5	.09	.9

1/ By USDA Forest Service definition, particleboard includes waferboard, oriented-strand board, composite board, and medium-density fiberboard.

2/ U.S. Department of Commerce, International Trade Administration.

3/ Based on interpolations, USDA Forest Service (1982).

Table 70.--Particleboard used in new mobile homes in the Lake States, Michigan, Wisconsin, and Minnesota[1/]

(In 3/4-inch basis)

Year	Shipments[2/]	Square feet per home[3/]	Total
	Thousand		Million square feet
LAKE STATES			
1981	11.4	0.85	9.6
1977	17.5	.86	15.0
1973	39.0	.71	27.7
MICHIGAN			
1981	4.3	0.85	3.6
1977	7.5	.86	6.4
1973	22.3	.71	15.8
WISCONSIN			
1981	3.1	0.85	2.6
1977	5.0	.86	4.3
1973	10.0	.71	7.1
MINNESOTA			
1981	4.0	0.85	3.4
1977	5.0	.86	4.3
1973	6.7	.71	4.8

1/ By USDA Forest Service definition, particleboard includes waferboard, oriented-strand board, composite board, and medium-density fiberboard.

2/ U.S. Department of Commerce, International Trade Administration. Mobile home shipments to the Lake States are estimated from shipments to North Central region, assuming that each State's share is the same as its share of residential construction within the region.

3/ Based on interpolations, USDA Forest Service (1982).

Table 71.--Particleboard used in furniture manufacturing in the Lake States, Michigan, Wisconsin, and Minnesota[1/]

(In 3/4-inch basis)

Year	U.S. consumption[2/]	State share[3/]	State consumption
	Million square feet	Percent	Million square feet
		LAKE STATES	
1981	1,739	11.5	200.0
1977	1,476	10.9	160.9
1973	1,145	9.0	103.1
		MICHIGAN	
1981	1,739	8.0	139.1
1977	1,476	7.5	110.7
1973	1,145	6.0	68.7
		WISCONSIN	
1981	1,739	2.5	43.5
1977	1,476	2.4	35.4
1973	1,145	2.1	24.0
		MINNESOTA	
1981	1,739	1.0	17.4
1977	1,476	1.0	14.8
1973	1,145	.9	10.3

1/ By USDA Forest Service definition, particleboard includes waferboard, oriented-strand board, composite board and medium-density fiberboard.

2/ Based on interpolations, USDA Forest Service (1982).

3/ U.S. Department of Commerce, Bureau of the Census, Census of Manufactures. Assumes that the region's share of value-added in SIC 25, Furniture and Fixtures, represents its share of the nation's total lumber consumption in furniture manufacturing. Trends shown in 1972 and 1977 are extended to 1981.

Table 72.--Residential fuelwood consumption in the Lake States[1/]

(In million standard cords)

Year	Michigan	Wisconsin	Minnesota	Total
1982	3.20			
1981	2.90	2.02[3/]		
1980	1.65[2/]	1.37	1.37	4.39

1/ Residential fuelwood surveys conducted by state departments of natural resources, in cooperation with Northeastern Area State and Private Forestry, USDA Forest Service.

2/ James, et al. (1982).

3/ Blyth (1981).

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Production and consumption of major wood products in the Lake States: perspectives and trends. Gen. Tech. Rep. NC-108. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 82 p.

Estimates are developed of primary and secondary wood product production and consumption in the Lake States (Michigan, Wisconsin, and Minnesota) between 1960 and 1980. Consumption estimates are derived through application of the use-factor approach. Increased cooperation among forestry agencies in the three states appears to hold significant regional benefits.

KEY WORDS: Paper and board, lumber, plywood and veneer, particleboard, fuelwood, derived demand, use-factor, demand indicators, policy implications, regional cooperation, research needs.

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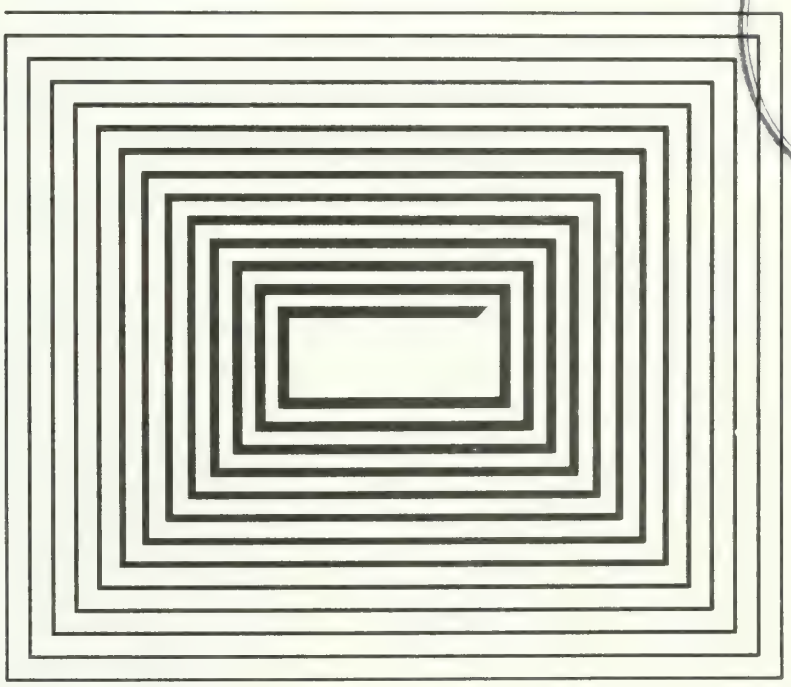
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A Framework for Identifying Public Research Priorities: An Application in Forestry Research

Glenn Fox

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CONTENTS

	Page
Economic Models for Assessing Research Priorities	1
Introduction and Overview	1
Scoring Models and Multiple Goal Linear Programming	2
An LP Model for Evaluating Research Projects	5
Precedence and Congruence	6
Dynamic Cost-Benefit Models	7
Models of Regional Spillover Effects	10
Optimal Growth Models	11
Identifying Southern Pine Forestry Research Priorities	14
Background	14
Congruence Calculations	14
A Social Surplus Model of Research Resource Allocation	15
References	19

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A FRAMEWORK FOR IDENTIFYING PUBLIC RESEARCH PRIORITIES: AN APPLICATION IN FORESTRY RESEARCH[1]

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ECONOMIC MODELS FOR ASSESSING RESEARCH PRIORITIES

Introduction and Overview

In recent decades, major research effort has been devoted to modeling and measuring the relation between research and development activity and the rate and nature of technical change. The notions that such change responds, at least in part, to the amount of resources allocated to research, and that invention responds to economic incentives, have become well established. This report reviews efforts to model optimal research resource allocation, and presents a model for southern pine forestry research.

The discussion will focus on two aspects of the available models: (1) the general structure of the optimization procedure, including the objective function to be optimized, the nature of constraints imposed on the model and the characteristics of solutions which emerge, and (2) the information required to employ the model for applied research budgeting questions.

The problem of determining an optimal level of research and development activities within an organization can be viewed as a component of the overall capital budgeting decision. Research competes for resources with the purchase of durable assets and current inputs and like durable assets and current inputs, contributes to achievement organizational goals. While varied techniques have been developed to guide the research resource allocation decision, a common theme has been an attempt to measure both the degree to which alternative research activities contribute to organizational goals and the opportunity cost of resources devoted to research. The procedures vary in the formality and detail with which these measurements are accomplished.

Although research funding needs to be seen as part of the broader capital budgeting process, the nature of research confounds the resource allocation problem. Perhaps the most outstanding feature of scientific research as an investment activity is the uncertainty inherent in most projects. *Ex ante,* it is never clear how much investment will be required to achieve a particular result, and even if success is achieved there is no guarantee that the net contribution to organizational goals will warrant the investment. Furthermore, because most research organizations have multiple goals, estimating contributions of a research project to specific goals and subsequently weighing the goals is difficult.

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Scoring Models and Multiple Goal Linear Programming

One of the earliest approaches to research budget allocation has been called the Scoring model. Panels of researchers and administrators identify organizational goals for research, attach weights to goals and to estimate relative contributions to goals of specific research projects. This information can be incorporated into a linear programming framework by adding resource requirements of projects and measures of organizational resources.

A scoring model approach was used in a national assessment of U.S. agricultural research priorities in 1965 and 1966 (USDA 1966). A similar exercise was conducted at the state level in North Carolina, beginning in 1972 (Shumway and McCracken 1975). Russell (1973, 1975) extended a scoring model to a linear programming approach in the U.K., applying a framework outlined by Kaldor (1966), Hildreth (1966), and Paulson and Kaldor (1968).

This approach usually involves two panels. The first typically consists of senior administrators whose task is to identify a set of organizational goals for research and to establish weights for each goal. Tables 1 and 2 report the criteria and weights employed in the USDA and North Carolina studies. Table 3 reports Russell's criteria. The second panel establishes scores for each proposed project for each criterion.

The weights are then used to construct an ordinal ranking of projects. Scores are computed either additively,

$$S_i = \sum_{j=1}^{J} W_j C_{ij}$$

or multiplicatively

$$S_i = \prod_{j=1}^{J} W_j C_{ij}$$

where S_i is the score of project i, j is the index for criteria, W_j denotes the weight attached to the jth criterion and C_{ij} is the score of the ith project on the jth criterion.

Russell's approach maximized the linear function

$$\sum_{j=1}^{J} W_j C_j$$

Table 1.--Criteria and weights used to set research organizational goals in "A National Program of Research for Agriculture"

Criteria	Weight
Extent to which the research meets State experiment station, USDA, and national goals.	9
Scope and size, considering area, people, and units affected.	8
Benefits of research in relation to costs.	7
Urgency of research.	10
Contribution to knowledge.	9
Feasibility of implementation and likelihood of successful completion in a reasonable period.	5
Likelihood that research results will not be available elsewhere.	6
Likelihood of extensive and immediate adoption of results.	6

Source: U.S. Department of Agriculture (1966, p. 29).

Table 2.--Research areas, criteria, and weights used to set organizational research goals in North Carolina

Research area	Criteria	Weights
Biological sciences and technology	1. Urgency--basic information needed to aid in solution to threat or problem	20
	2. Cost relevance--expected long-term benefits in relation to costs	15
	3. Degree to which similar research is not now being conducted or not likely to be conducted elsewhere (higher scores assigned if inadequate research results expected elsewhere)	15
	4. General importance and potential for contribution to knowledge; higher scores assigned for greater scientific merit and potential for contribution to faculty development and improved academic performance	50
	Total =	100
Animals and plants	1. Extent to which proposed research is consistent with station, regional, and national goals in agriculture and forestry; economic value of the crop or animal enterprise and its products to people of North Carolina.	35
	2. Cost relevance--expected benefits in relation to costs	20
	3. Degree to which similar research is not now being conducted or not likely to be conducted elsewhere (higher score for research and sub-research problem area for which adequate results are not likely to be available elsewhere) and for which there is an urgent need for research results	20
	4. Potential for contribution to knowledge	25
	Total =	100
Environment and natural resources	1. Extent to which proposed research is consistent with station, regional and national goals in natural resource development and conservation	35
	2. Cost relevance--expected benefits in relation to cost	15
	3. Degree to which similar research quality on this resource is not now being conducted or likely to be conducted elsewhere (higher scores for inadequate research elsewhere) and concerning which there is public pressure, a threat to the natural resource, or a critical need for environmental protection	15
	4. Potential for contribution to knowledge	20
	5. Extent to which the research will aid in meeting broader public service commitments of the school and university beyond traditional statutory charge of the experiment station	15
	Total =	100
Food-fiber-people economics	1. Extent to which recommended research is consistent with station, regional and national goals of promoting and protecting public health and improving family living; potential for improving quality of life and developing rural communities in North Carolina	35
	2. Cost relevance--expected benefits in relation to increased costs of research in these areas	20
	3. Degree to which similar research is not now being conducted or likely to be conducted elsewhere (higher scores for inadequate research elsewhere) and for which there is public support for research to evaluate the impact of improved agricultural technology, a threat to public health, or a need for information to support new processing industries	20
	4. Potential for contribution to knowledge	25
	Total =	100

Source: Shumway and McCracken (1975).

Table 3.--Organizational research goals and rating system employed by Russell

Goal dimension and aspect		Proposed rating system
CONSUMPTION CATEGORY		
1. Quantity	-Productivity	-Percentage increase in social profitability per unit of output.
	-Total production	-Cumulative discounted net social profitability for relevant time period.
2. Quality	-Appeal, nutritive value, reliability, versatility	-Scoring model from present or low levels to arbitrarily defined ideal levels.
3. Availability	-Growth cycle limitations	-Percentage increase in effective season.
	-Supply/demand equilibrium instability	-Ratio of cost with instability to cost with stability.
	-Number of substitutes	-Percentage increase in number of substitutes.
SECURITY CATEGORY		
4. Human Safety	-Risk of accident	-Percentage reduction in a particular type, weighted according to the severity of the type of accident.
	-Risk of disease	-Percentage reduction in contradictions, weighted according to the severity of the disease.
5. Economic Defense	-Balance of payments	-The ratio of the value of potential reduction in imports to present value of imports.
	-International dependence	-The ratio of the expected reduction in trade to total trade.
6. Food Sources Security		-Reduction in probability of loss attributable to the research.
7. Conservation	-Utilization efficiency	-The ratio of the per unit nonrenewable resource saving to per unit requirement before the research.
	-Depletion rate	-The ratio of the reduction in rate of nonrenewable resource depletion to the depletion rate prior to the research.
EQUITY CATEGORY		
8. Distribution	-Consumption, wealth	-Scoring model based on value of increased income to various groups.
9. Individual Rights	-Opportunity, discrimination	-Scoring model from present levels to ideal levels.

Source: Russell (1975).

where C_j represents the contribution of all i = 1 to I projects to criterion j. C_j is computed as

$$C_j = \sum_{i=1}^{I} (C_{ij}/\bar{r}_i)\, r_i$$

where r_i is the level of funding of the ith project and $\bar{r}_i$ is an upper limit to the size of the project. The maximization problem is constrained by the total research budget $\bar{R}$,

$$\sum_{i=1}^{I} r_i \leq \bar{R}$$

and the feasibility constraints

$$0 \leq r_i \leq \bar{r}_i,\ i=1 \ldots I.$$

Work by Fishel (1970, 1971) and Grieg (1979) are extensions and adaptations of scoring models. Fishel developed a stochastic cost-benefit model. Rather than seeking expert opinion in the form of scores, Fishel sought estimates of the parameters of a cost-benefit model. His approach synthesizes subjective probability distributions of key variables from panel and survey data. Researchers and administrators were asked to estimate annual costs and benefits and expected times to completion of several projects. These responses were used to generate point and interval estimates of the variables used in the cost-benefit analysis.

The Fishel approach to measuring benefits computes the sum of the gains in human capital among the researchers engaged in the project, the present salvage value of equipment purchased and the expected net benefits from the knowledge derived.

Grieg developed a stochastic simulation model to study two poultry research projects. Discussions with researchers were used to establish parameters for a single firm and an aggregate simulation. The framework developed was quite complex and costly to implement. It was also difficult to independently verify the information obtained from the research expert. Extending scoring models to create stochastic cost benefit analysis is fraught with the same limitations as scoring models in general. It is expensive to accumulate the required data, and validation is difficult.

Scoring and multiple-goal LP models require a list of potential projects, a set of criteria with associated weights, and in the programming version resource requirements of projects including any relevant feasibility constraints. The output of the analysis is an ordinal ranking of projects which can be used to exhaust the research budget. Because the method has been popular in agricultural research as well as in military and industrial research considerable effort has been made to evaluate the technique. Moore and Baker (1969) in assessing scoring models in military and industrial research, found the advantages of this approach to include: (1) broad participation of research personnel at several administrative levels, (2) limited requirements for technical skills of formal cost-benefit analysis, and (3) explicit identification of and relationship to organizational goals.

Some of these advantages, however, can also be seen as liabilities. Broad participation can be expensive, particularly in its use of senior administrators' time. The absence of formal benefit-cost calculations gives an impression of subjectivity and arbitrariness in the selection of criteria and weights. Also, there is no mechanism to weed out redundancy and overlap among criteria. While the relationship to organizational goals is emphasized in this approach, it really gives no guidance in the solution of $\bar{R}$, the overall research budget. While in principle an ordinal ranking could be constructed to include all investment opportunities available to an institution, this has not been done in practice.

In addition, several technical problems remain unsolved. Should S_i be computed as an additive or multiplicative formula? Should project alternatives be identified on the basis of problem areas, commodity groupings or scientific disciplines? Should the variation of S_i scores among panelists play a role in the ordinal ranking? Finally, Moore and Baker report that scoring models are not always able to give similar ordinal rankings to cost-benefit procedures.

An LP Model for Evaluating Research Projects

Klein and Kehrberg (1981) have developed a model to help researchers choose among crossbred lines at early stages of a livestock breeding program. In principle, the approach could be applied to plant breeding, but cost savings would be lower because of lower maintenance costs for plants.

Linear programming is used to trace a unit isoquant of a crossbred line under alternative factor price regimes. The objective function minimizes unit costs. Results of performance trials of first-generation offspring are used to compute an input

requirements matrix, A. Several modes of production were considered, with each column of A representing the vector of input requirements necessary to achieve a unit of the production activity. The set of production activities, each representing a unique combination of housing, feed, and breeding methods, is represented by the vector L. Total output is represented by Y°, and D is a vector of estimates of output levels per unit of each activity in L. Therefore $DL = Y^{\circ}$. Total input use is AL, which must equal IX, where I is the identity matrix. In summary, the LP model seeks to

$$\begin{aligned} &\text{Minimize } (C + \theta)X \\ &\text{Subject to } DL = Y^{\circ} \\ &\qquad AL - IX = 0 \end{aligned}$$

θ is a vector of parameters used to describe alternative factor price regimes.

Ten crossbreeds were compared using the model. Some were found to be of lower unit cost for all factor price combinations. Some lines never achieved lowest unit cost for any input price set. The authors argued that this information, tempered with the judgments of the research team, could be used to identify the most promising crossbred lines for further investigation. Embryo storage could preserve the genetic material of the least promising crossbreeds.

Precedence and Congruence

Precedence and congruence models are arguably the least costly means of establishing funding guidelines for public research. The precedence approach reinforces the status quo. According to this model, the share of research funds allocated to a particular commodity remains constant through time. Each component of the budget expands or contracts at the same rate as the overall budget.

The congruence model, as developed and used by Boyce and Evenson (1975), Evenson *et al.* (1979), Ruttan (1982, 1983), Pinstrup-Anderson (1982) and Salmon (1983) allocates research resources to commodities according to the economic significance of those commodities. Under Salmon's approach, a congruence ratio is computed for each commodity i, as

$$CR_i = \frac{\dfrac{r_i}{\overline{R}}}{\dfrac{P_i Y_i}{\sum_{k=1}^{n} P_k Y_k}}$$

where r_i is the research expenditure on commodity i, $\overline{R}$ is the total research budget, $P_i Y_i$ is the gross revenue from market sales of commodity i and

$$\sum_{k=1}^{n} P_k Y_k$$

is the gross revenue earned from all commodities being considered in the research budget. There is an ambiguity in this definition in that it is not clear if gross revenue or value added should be employed in computing CR_i.

Advocates of congruence ratios tend to downplay the prescriptive power of the approach. Their use is seen as a way of relating the size of research expenditure to the size of an industry. An important suggestion in these studies is that outliers in the vector of congruence ratios are to be viewed with suspicion as being potentially sub optimal. In other words, congruence ratios should be equal to one unless there are "good reasons" for them not to be.

Both the precedence and congruence models have limited data requirements for implementation. Indeed, the precedence approach requires only a copy of last year's budget and the size of this year's funding increase or decrease. The congruence model additionally requires information on gross revenues of commodity groups.

Many of the disadvantages of these approaches derive from their simplicity—for instance, they aren't capable of dealing with imminent breakthroughs in a particular area. If a crop has been of little economic importance in the past and its research budget is small, an extremely productive sequence of research discoveries would go unacknowledged in either of these funding models. Also, neither technique gives any help in determining $\overline{R}$, the overall level of funding.

Bredahl and Peterson (1976) have interpreted congruence ratios as the inverse of average products of research. By assuming a particular model of production, average products can be related to marginal products and subsequently to marginal interest rates of return. Substantial gains in the usefulness of the approach for resource allocation questions can thereby be achieved.

Dynamic Cost-Benefit Models

Public investment in agricultural research is made over a protracted period, and benefits occur after a lag of several years. Several analysts have acknowledged this fact by pursuing formal techniques of dynamic cost-benefit analysis to improve the efficiency of research resource allocation.

Net Farm Income

Barker and Herdt (1982) developed a model to allocate research resources for rice. A similar framework was advanced by Araji *et al.* (1978). Barker and Herdt proposed that research resources should be allocated across types of rice to maximize the discounted streams of expected changes in net farm income (NFI) for the commodities in question. This amounts to choosing a vector of research funding levels, $R_0 = \{r_{10}, r_{20}, r_{30}, \ldots r_{n0}\}$, to maximize

$$\psi(R_0; \Gamma) = \sum_{i=1}^{n} \left\{ \sum_{t=0}^{\infty} (1+\rho)^{-t} \Delta \, NFI_{it}(r_{i0}, \Gamma) \right\}$$

where ρ is the discount rate, $\Delta \, NFI_{it}(\cdot)$ denotes the change in aggregate net farm income for commodity i in period t as a function of r_{i0}, and Γ is a vector of parameters.

While this criterion has a certain intuitive appeal, it fails to take into account the benefits accruing to consumers in the form of lower commodity prices. When an industry faces inelastic demand, net farm income can be depressed by technological change, and yet the net benefit to society as a whole is positive. From this perspective, the net farm income criterion will, in general, be a poor guide to the allocation of research resources.

Social Surplus Criterion

A surprising feature of much of the literature addressing the problem of *ex ante* optimal research allocation is that it bears little relation to the analytical framework used in studies of *ex post* estimates of gains to research. The latter studies measure the gains from research in terms of changes in consumers' and producers' surpluses and in input use savings. For *ex ante* allocation decisions, it would be useful to have a model of the future pattern of these changes in social surpluses and input savings where these benefits depend on current research expenditure. The approach taken here is an adaptation of Peterson (1967) and Ayer and Schuh (1972).

The payoff from research is not immediate. Research funded today induces a sequence of supply shifts in the future. These supply shifts bring about gains in consumers' and producers' surpluses as commodity prices change and also yield resource savings when demand is inelastic. Figures 1 and 2 identify these gains for a sequence of supply shifts.

The demand curve in the figures is written in inverse form as

$$P^D_{it} = \gamma_i \, Y_{it}^{\frac{1}{\eta_i^D}}$$

where i denotes the commodity, t represents time, P is the price of commodity i paid by consumers and Y is the quantity that would be purchased at price P. This is a constant elasticity demand curve, where η_i^D is the elasticity of demand for commodity i. The figures are drawn for the case $-1 < \eta_i^D < 0$. The situation for $\eta_i^D < -1$ can be derived in a straightforward

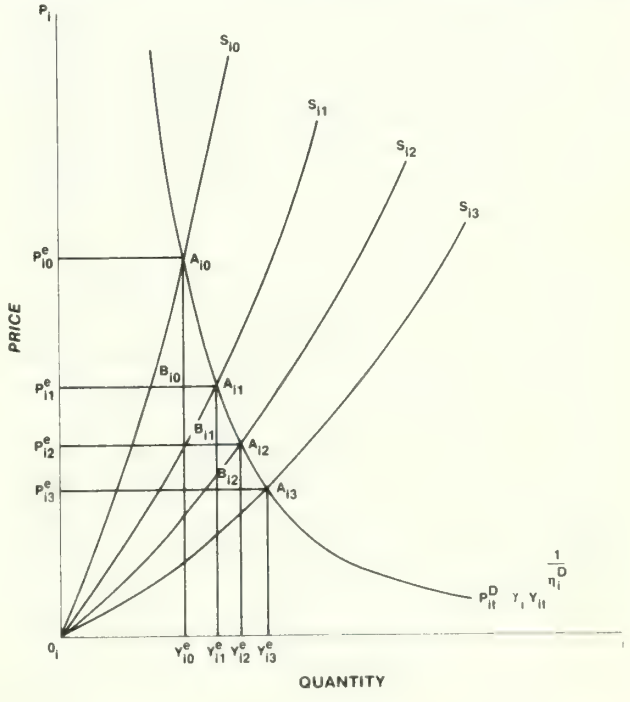


Figure 1.—*Changes in consumers' and producers' surpluses for a sequence of supply shifts.*

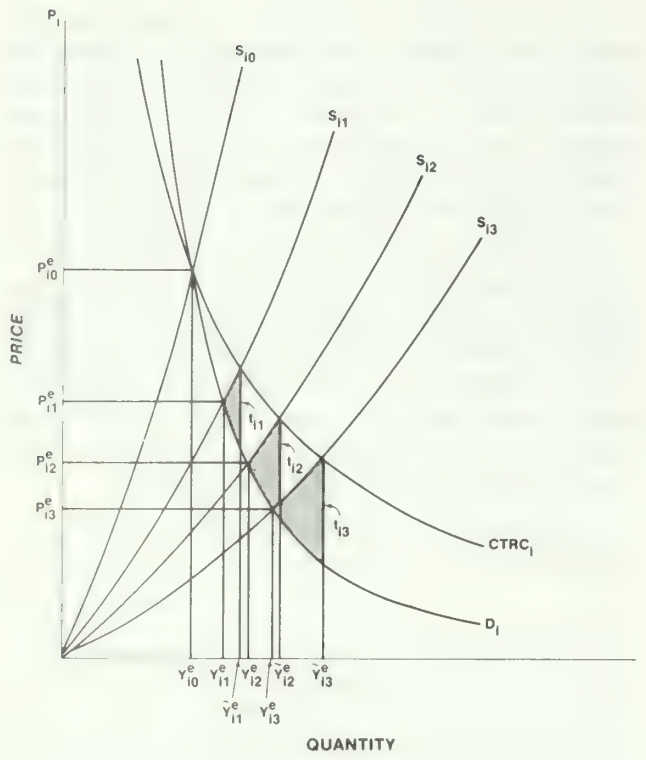


Figure 2.—*Gains from resource transfer under technological change.*

manner. Referring to figure 1, as the supply curve shifts in response to research in $t = 0$, the market clearing price falls successively from P^e_{i0} to P^e_{i3}. The equilibrium quantity of consumption and production rises from Y^e_{i0} to Y^e_{i3}. This sequence of price changes induces a sequence of changes in consumers' surplus. Between $t = 0$ and $t = 1$, consumers gain the area $P^e_{i0}A_{i0}A_{i1}P^e_{i1}$. Between $t = 1$ and $t = 2$, they gain $P^e_{i1}A_{i1}A_{i2}P^e_{i2}$. In general, between periods t and $t + 1$, consumers gain $P^e_{it}A_{it}A_{it+1}P^e_{it+1}$.

Producers' surplus also undergoes a sequence of changes. Between $t = 0$ and $t = 1$, producers lose the area $P^e_{i1}B_{i0}A_{i0}P^e_{i0}$ and gain $0_iB_{it}A_{it+1}$. If we consider the net gain to consumers (ΔCS) and producers (ΔPS) to be of equal weight, then the net change in these surplus areas between period t and $t + 1$ is $0_iA_{it}A_{it+1}$. That is, the incremental change in social surplus is the area between the two adjacent supply curves and under the demand curve. If this incremental change in social surplus is denoted as ΔSS_{it}, then

$$\Delta SS_{it} = \Delta CS_{it} + \Delta PS_{it} \ .$$

In measuring the total benefit to consumers and producers of commodity i in time period t, the standard of comparison is the pre-research equilibrium. The social surplus gains are cumulative. Let the benefit accruing to producers and consumers of commodity i in period t be denoted as B_{it}. We can compute the benefit for each time period as

$$B_{it} = \sum_{j=1}^{t} \Delta SS_{ij}$$

The present value of the sequence of benefits beginning at $t = 0$ is

$$B_i = \sum_{t=0}^{T_i} (1+\rho)^{-t} B_{it} + \sum_{t=T_i+1}^{\infty} (1+\rho)^{-t} B_{iT_i}$$

where T_i is the last time period in which a shift in supply is experienced from research in $t = 0$ and ρ is the social discount rate. It is conceivable that research investment may depreciate, so the sequence of supply shifts generated by research in a period may move the supply schedule initially to the right, but eventually the curve will shift back so that $B_{iT_i} = 0$.

This measure of the social benefits from research is incomplete, however. Under conditions of inelastic demand, as the supply curve shifts down and to the right, total expenditure on the commodity at successive equilibria falls. If constant returns to scale and constant factor shares prevail at the industry level, and if variable inputs are supplied perfectly elastically to the industry, then the quantity of variable inputs falls in the industry undergoing the supply shift. To calculate the total social benefit from research in the market for commodity i in period t, we need to measure the net value to society of these released inputs and add this value to the net change in social surpluses (fig. 2). In figure 2, a rectangular hyperbola is drawn through the pre-research equilibrium. A property of this curve is that the product of price and quantity is a constant along the curve, and hence it is labeled as the Constant Total Revenue Curve ($CTRC_i$). Given the assumptions pertaining to scale economies, factor shares and input prices, the quantity of variable inputs is constant along this curve, and is equal to the level of variable input use in the pre-research equilibrium. I have labeled the abscissa of the intersections of the CTRC with the sequence of supply curves as $\tilde{Y}^e_{it}$. They represent the level of output forthcoming in period t under the technology of period t if the input use level is held constant at the pre-research level.

The net social gain of declining input use levels can be seen through a simple thought experiment. Suppose an artificial barrier forced a constant level of input use in an industry as the supply curve shifts. In our example, with inelastic demand for the commodity, the level of output with constant input use, $\tilde{Y}^e_{it}$, exceeds the market equilibrium level of output, Y^e_{it}. The total cost of variable inputs required to attain ($\tilde{Y}^e_{it} - Y^e_{it}$) is the area under the supply curve between $\tilde{Y}^e_{it}$ and Y^e_{it}. The valuation placed on this output, however, is the area under the demand curve between $\tilde{Y}^e_{it}$ and Y^e_{it}. The shaded area, in figure 2, identified as τ_{it}, is the net loss from our artificial barrier, or the net gain from allowing the release of resources to the rest of the economy. Therefore, the total benefit obtained from research in time t is the cumulative change in social surplus areas, B_{it}, plus τ_{it}. If we define $\bar{B}_{it}$ as

$$\bar{B}_{it} = B_{it} + \tau_{it}$$

so that the present value of benefits of research on commodity i, denoted as $\bar{B}_i$, is

$$\bar{B}_i = \sum_{t=0}^{T_i} (1+\rho)^{-t} \bar{B}_{it} + \sum_{t=T_i+1}^{\infty} (1+\rho)^{-t} \bar{B}_{iT_i}$$

A version of $\psi(R;\tau)$ can be constructed by simply summing the $\bar{B}_i$'s. In mathematical notation, the objective function is

$$\psi(R;\tau) = \sum_{i=1}^{n} \bar{B}_i$$

which is to be maximized subject to $\sum_{i=1}^{n} r_{i0} \leq \bar{R}$.

Since this version of the objective function comprises a comprehensive accounting of all the gains from technological change, it is a more reliable target than the versions based on changes in net farm income discussed earlier. Furthermore, at least in principle, the relationship between research expenditure and the vector of benefits

$$\bar{B} = (\bar{B}_1, \bar{B}_2, \ldots \bar{B}_n)$$

can be computed from measurable commodity market parameters. This introduces an element of economy into the implementation of the model that is not available in the multiple goal linear programming framework. Also, an optimal $\bar{R}$ can be identified as the level of funding which gives a value of $\psi(R;\tau) = 0$ for a social discount rate of ρ.

Several studies have used versions of this model to study research resource allocation. Ramahlo de Castro (1974) and Ramahlo de Castro and Schuh (1977) developed a model for cotton, sugarcane, corn, rice, and edible beans for Brazil. Supply and demand elasticities were allowed to vary by commodity, but a given level of research expenditures was assumed to shift the supply curve by the same proportion for each commodity. This implies that generating technical change through research is equally easy for each of the named commodities. Annual gross benefits of each supply shift were measured and estimates of the share of gains going to producers and consumers were computed. The general findings indicated that crops with higher gross revenues provided larger research benefits than smaller crops, and that the distribution of gains between producers and consumers depended on the relative absolute magnitudes of the supply and demand elasticities. Producers received a larger share of the gross gains when the absolute magnitude of the demand elasticity was larger than the supply elasticity.

Scobie (1979) developed a model in which the size of the supply shift depends upon the level of research investment. The supply function is written as

$$P^S_t = \beta Y_t^{\frac{1}{\eta^S}}$$

The rate of supply shift is determined by β. If no research is done, $\beta = 1 + \alpha_{min} \cdot \alpha_{min}$ is a minimal annual percentage shift attributed to factors other than research. As research investment increases, approaches $1 + \alpha_{max}$ asymptotically. For intermediate values for research investment, R,

$$\beta = 1 + \alpha_{max} - \left\{ \frac{\alpha_{max} - \alpha_{min}}{1 + \frac{R}{P \cdot Y}} \right\}$$

Scobie does not clarify if R is a stock variable or an annual investment level.

Habib (1980) and Habib *et al*. (1981) evaluated the relative net benefits of research on jute, rice, sugarcane, and tea for Bangladesh. Their supply model has much in common with the Scobie model. The supply function for each commodity was written as

$$Y^S_i = (1+h_i)\, \alpha_i\, P_i^{\eta_i^S}$$

The h_i term represents a percentage shift in the supply function in response to research. The size of the shift is a linear function of the research investment, so that

$$h_i = S_i R_i$$

up to a maximum possible shift of h_i^u. It is not made clear if R is an annual investment level or a stock concept. Values for the S's were obtained by comparing crop yields in Bangladesh with yields elsewhere in Asia. The study concluded that potential gains from research were highest for rice and then for sugarcane.

All of the models discussed in this section make important strides in conceptualizing the research budgeting process as an optimization problem. They also highlight some critical data requirements which were ignored in the models of earlier sections. The magnitudes of supply and demand elasticities, the functional forms of these schedules, the mechanism by which research investment shifts supply all receive a deserved emphasis. All of this, however, tends to show that these models are more costly to estimate and use than the precedence or congruence approaches, but are likely to be less costly than the use of scoring models. Furthermore, reliance on the notions of consumers' and producers' surpluses makes these models vulnerable to all of the theoretical arguments that undermine the credibility of those measures of economic welfare (Chipman and Moore 1976, 1980; McKenzie 1982).

Models of Regional Spillover Effects

Lessons learned from agricultural research in one region can often be adapted and applied in another region with similar agro-climatic characteristics. These spillover effects have important consequences for optimal public financing of regional research centers by a federal government. Simply put, a region which generates large spillover benefits should receive a commensurately higher level of federal funding than a region which doesn't generate this effect. Several economists, including Garren and White (1981), Garren (1981), Ziemer *et al.* (1982), White and Havlicek (1981), and Havlicek and White (1983) have recently turned their attention to this regional allocation question for the case of the U.S. economy.

As with the dynamic cost-benefit models, the analytical framework employed in these regional spillover models represents the contribution of research as a shift variable in the production or supply function. In the Ziemer *et al.* (1982) study, the supply function for aggregate agricultural output in a region i is represented as

$$Y_{it} = \alpha_i P_{it}^{\eta_i^s} Y_{it-1}^{1-\delta_i} \exp\left\{\delta_i \sum_{j=0}^{t-1} g_{ij} + g_{it}\right\}$$

The shift function, exp {·} reflects the effects of research inside and outside of the region through the formula that determines the g_{it}'s. The effect of research on output was estimated using an adaptation of the technique introduced by Cline (1975). A multifactor productivity index (PR) for each region was regressed on lagged research inside (RI) and outside (RO) of the region, the level of farmers' education in the region (E) and a weather index (W). The functional form employed was

$$PR_{it} = \prod_{j=0}^{13} RO_{it-j}^{\alpha_{ij}} \prod_{j=0}^{13} RI_{it-j}^{\beta_{ij}} E_{it}^{\alpha_i} \exp\{\delta_{0i} + \delta_{1i} W_{it}\}$$

The value of the α's and the β's were then used to compute the g functions, according to

$$g_{it} = 0.10\ \alpha_{it} S_i + 1/(1-R_i) \sum_{\substack{j=1 \\ j \neq 1}}^{10} 0.10\ \beta_{it} S_j R_j$$

S_k represents the share, in value terms, of national crop and livestock output originating in region k. R is the regional percentage of research expenditure as a share of the national total. The 0.10 coefficient indicates that the analysis was conducted to consider a hypothetical 10 percent increase in research expenditure. Weighting the contribution of other regions research by $(1 - R_i)^{-1}$ means that a region which has a high value for R_i would benefit more from spill-ins than a region with a lower level of internal research investment.

The findings of this set of studies indicate that federal research funding in the United States has not reflected regional patterns of benefit transmission. A realignment of funds to increase research in regions generating large spillovers was recommended. None of the papers cited above, however, took the final step of computing an optimal regional allocation pattern.

The analytical framework employed in these regional studies is essentially the same as that in the cost-benefit models outlined above, and is subject to the same information requirements and theoretical limitations. Additional care was taken in the regional models to identify the time lag structure of research benefits, and this is an important contribution.

Optimal Growth Models[2]

The study of optimal economic growth has traditionally been the province of development specialists, macroeconomists, and theorists. More recently, resource and agricultural economists have begun to apply this approach to the study of technological change. Optimal growth models have typically been used to study resource allocation at the national or sectorial level, but some less aggregate efforts have been undertaken.

One of the earliest applications of control theory to technical change was made by Uzawa (1965). In his model, the allocation decision focuses on dividing the total labor force at time t, L(t), between employment in production, Lp(t), and employment in the educational or research sector, Le(t). The production function is represented as:

$$Y(t) = F\,[K(t),\ T(t)\ Lp(t)]$$

where T(t) is an index of labor efficiency. This index increases as a larger share of the labor force is employed in the research sector. Research workers produce knowledge that makes production workers more effective. The movement of T(t) through time is governed by

$$\dot{T}(t)/T(t) = \emptyset\,[Le(t)/L(t)] = \emptyset\,[1-u(t)]$$

where $u(t) = Lp(t)/L(t)$. $\dot{T}(t)/T(t)$ denotes the growth rate of T(t). It is assumed that increasing the share of the labor force employed in research increases the rate of growth of T(t), so that $\emptyset' \geq 0$. This effect is subject to decreasing returns, however, so $\emptyset'' \leq 0$.

Other assumptions in the model include full employment of a finite labor force at each moment of time,

$$Lp(t) + Le(t) = L(t)$$

a constant growth rate of the total labor force

$$\dot{L}(t)/L(t) = n$$

Output is allocated between consumption, C(t), and gross investment, I(t)

$$I(t) + C(t) \leq Y(t)$$

at each moment of time, and the capital stock, K(t), evolves according to

$$\dot{K}(t) = I(t) - \delta K(t)$$

A constant rate of depreciation is represented by δ.

These constraints are imposed on the objective function, which seeks to maximize the discounted stream of consumption per caput. The problem is set up for an infinite horizon and with a constant rate of social time preference, ρ.

Thus

$$\int_0^\infty [c(t)/L(t)]e^{-\rho t}\,dt$$

Functional forms for the production function and the technology index are not specified, so a quantitative solution to the model is found. It is useful to develop some additional notation. The effective capital-labor ratio is defined as

$$x(t) = K(t)/[T(t)\cdot L(t)]$$

The savings ratio is defined as

$$s(t) = I(t)/Y(t)$$

The optimal solution obtained is a balanced state described by the time paths of u(t), x(t) and s(t). Let a superscript* denote the value of a variable in its optimal state. If, by coincidence, the initial effective capital-labor ratio is optimal, that is

$$x(0) = x^*$$

then optimal growth is achieved by choosing a savings rate and an allocation of the labor force so that the technology index increases at the same rate as the capital labor ratio. Mathematically,

$$\dot{T}(t)/T(t) = \dot{k}(t)/k(t)\ ,$$

where $k(t) = K(t)/L(t)$.

[2]*Readers unfamiliar with the techniques of control theory are referred to Intrilligator (1971), Takayama (1974), and Kamien and Schwartz (1981).*

By manipulation of the definitions above, this allocation rule can be written as

$$\emptyset\,[Le(t)/L(t)] = \frac{I(t)}{K(t)} - (\delta + n)$$

If $x(0) > x^*$, the savings rate falls to zero until $x(t) = x^*$ is achieved. If $x(0) < x^*$, then all output is saved ($S(t) = 1$), until $x(t) = x^*$. Once $x(t)$ achieves the optimal level, the labor and savings rule described above is followed.

By the late 1970's the model of endogeneous technological change introduced by Uzawa began to attract the attention of several economists, after an extended period of neglect. Ironically, it was concern for the problem of depletion of nonrenewable resource stocks that rekindled interest in the Uzawa model and not the study of technical change itself. Resource economists began to analyze conditions under which investments in technical change and in conventional capital could potentially stave off the apocalyptic vision described in the *Limits to Growth* literature for an economy with finite nonrenewable resources.

Robson (1980) studied a specialized version of the Uzawa model. The objective function was written as

$$\int_0^\infty e^{-\rho t}\left[\frac{C(t)}{1-\sigma}\right]^{1-\sigma} dt$$

The elasticity of the objective function with respect to an instantaneous increase in C is $1 - \sigma$, which is a constant. If $\sigma = 0$, then aggregate consumption is the preference indicator. For $\sigma = 1$, the objective function is logarithmic.

The production function is Cobb-Douglas, with

$$Y(t) = A(t)\ Lp(t)^{\alpha}\ K(t)^{\beta}\ E(t)^{\gamma}$$

The output elasticities are assumed to be strictly positive and to sum to a constant strictly less than 1. The effect of technical change is captured in the term A(t), the rate of extraction and use of a nonrenewable essential resource is represented by E(t). Because the resource is nonrenewable, the initial stock is fixed

$$S(0) = S_0$$

and the stock at any point in time constrains the total available for future consumption

$$S(t) = \int_t^\infty E(t)\ dt\ .$$

The rate of resource depletion is

$$\frac{\dot{S}(t)}{S(t)} = \frac{E(t)}{S(t)}$$

Output can be either invested or consumed, and the capital stock is assumed to not depreciate, for simplicity. Therefore

$$\dot{K}(t) = Y(t) - C(t)$$

$K(0) = K_0$ is given. Technical change shifts the production function. The intercept term A(t) changes in response to the proportion of the labor force devoted to research. A linear relationship is assumed,

$$\frac{\dot{A}(t)}{A(t)} = \delta\,\frac{Le(t)}{L(t)} = \delta\left[\frac{L(t) - Lp(t)}{L(t)}\right]$$

From the necessary conditions for a solution to this optimal control problem, it can be shown that

$$Y_k(t) = \rho + \tau\,\frac{\dot{C}(t)}{C(t)}$$

$$Y_k(t) = \frac{\dot{Y}_E(t)}{Y_E(t)}$$

and

$$Y_k(t) = \frac{\dot{Y}_L}{Y_L} + \frac{\delta L_p(t)}{\alpha L(t)}$$

In each case, $Y_k(t)$ is the marginal product of capital. The right hand side of the first condition is often called the consumption rate of interest. If consumption is increasing (i.e., $\dot{C}/C > 0$), then the marginal product of capital needs to be greater than the rate of time preference, ρ.

The second condition requires that the rate of growth of the marginal product of the nonrenewable resource be equal to the marginal product of capital. Since the stock of the nonrenewable resource is falling through time, and the production function is Cobb-Douglas, this condition implies that the marginal product of capital is increasing through time.

Robson also characterizes the asymptotic steady state to which the optimal solution converges. In the steady state, a constant share of output is allocated

to research. If labor is paid its marginal product, then the share in value terms of output devoted to research is

$$f = \frac{Y_L(t) \cdot L_E(t)}{Y(t)}$$

Y_L denotes $\alpha Y/\alpha L_p$. It can be shown that

$$f = \frac{\delta[(1-\beta) - \sigma(1-\sigma)] - \rho\alpha(1-\beta)}{\rho(1-\beta) - \delta(1-\sigma)}$$

In the case of a logarithmic objective function, $\sigma = 1$, and

$$f = \frac{\delta}{\rho} - \alpha$$

Chiarella (1980) chose to view the research resource allocation problem by treating research as an investment good. The discounted stream of the logarithm of consumption was used as the objective function

$$\int_0^\infty e^{-\rho t} \ln C(t)\, dt \ .$$

Consumption of a nonrenewable resource, E(t), capital, K(t), and the level of technology, Z(t), are inputs in a Cobb-Douglas production function.

$$Y(t) = Z(t)^\beta K(t)^{\alpha 1} E(t)^{\alpha 2}$$

As resources are used for production, the stock, S(t), is depleted, so

$$\dot{S}(t) = -E(t)$$

The level of technology changes with the rate of research investment, according to

$$\dot{Z}(t) = R(t)^\delta$$

Output is either consumed, invested in capital or invested in research, so

$$\dot{K}(t) = Y(t) - C(t) - R(t)$$

Here again, conventional capital does not depreciate, nor does research.

Since the objective function of the Robson model is reduced to the special case of the Chiarella model when $\sigma = 1$, it is not surprising that necessary conditions for an optimal solution include

$$Y_K(t) = \rho + \frac{\dot{C}(t)}{C(t)}$$

and

$$Y_K(t) = \frac{\dot{Y}_E(t)}{Y_E(t)}$$

These are identical to the Robson results for $\sigma = 1$. The third condition in the present context is

$$Y_K(t) = \frac{\delta R(t)^{\delta-1}}{\frac{\beta Y(t)}{Z(t)}} - \frac{(\delta - 1)\dot{R}(t)}{R(t)}$$

The first term is the ratio of the marginal product of research in the technology function to the gross rate of return to technology. The second term is a constant times the rate of growth of research expenditures. For a given value of the marginal product of capital, this condition requires that the higher the value of the marginal product of research in the technology function, the faster the growth rate in research investment should be.

Chiarella's result can also be manipulated to show the optimal steady state share of output that should be devoted to research. The solution is

$$\frac{R^*}{Y^*} = \left[\frac{\delta^2 \beta\alpha_2}{\delta(\beta+\alpha_2) + \alpha_1 - 1}\right] \ .$$

In the same volume as the Chiarella paper, Takayama (1980) develops two models of technical change using optimal control techniques.

Little emphasis has been placed on empirical estimation in the control theoretic literature on research resource allocation. Nevertheless, the work suggests potential applications. It has been an important contribution to formally characterize the problem as a special case of dynamic investment. Techniques of control theory based on continuous time suffer from the limitation of not being able to handle very detailed problems. As the number of choice variables increases, the set of differential equations describing the necessary conditions becomes very difficult to solve analytically. Some progress has been made, however, through the use of dynamic optimization models in discrete time. The work of Knutson and Tweeten (1979) and Fox (1986), to which we now turn, is in this tradition.

The applications of Knutson and Tweeten and Fox employed optimal growth models to determine socially efficient levels of public agricultural research

for the U.S. farm sector. Knutson and Tweeten considered the farm production sector as a unit. Fox's model had separate livestock and crop sectors. Both studies used a revised version of Cline's model of the production function for agriculture. The Knutson and Tweeten study considered three scenarios for real increases in funding:

1. Expenditures would grow in real terms by 3 percent per year from 1976-2015, which represents an extrapolation of the trend from 1939-1972.
2. Real funding growth of 10 percent per year for 1976-1980, followed by 3 percent real growth to 2015.
3. Ten percent growth from 1976-1980 followed by 7 percent growth annually to 2015.

The effect of these research investments on output prices and production levels was estimated with the National-Interregional Projections system (Yeh 1976) for various assumptions about the rate of growth in demand for farm products. Social rates of return to research investments were computed for each of the funding and demand growth combinations. Research investment was considered socially profitable if the rate of return was not depressed below 10 percent. If demand growth was held to 1.2 percent per annum, then the historical rate of increase in funding was found to be consistent with the optimality criterion. This would lead to a doubling of annual support for research by the end of the century. Higher rates of research funding were optimal for higher levels of demand growth. The effect of export market behavior on demand growth was not reported.

The Fox study used a three sector growth model. Livestock production, crop production, and the rest of the economy were represented. The model sought to maximize the discounted stream of the logarithms of annual consumption of output of the three sectors weighted by shares of annual consumption expenditure. The objective function was constrained by production functions for each sector and by factor endowments. Crops could be exported in exchange for goods which substituted for the output of the nonfarm sector. Four categories of research were identified. "Basic", or non-commodity specific biological research, and "applied", a commodity specific research aimed at the farm production sector, were identified for each of the two farm sectors. These public investment variables competed with consumption and with conventional capital investment inside and outside of agriculture.

The findings of this report contrasted with the results of the Knutson and Tweeten study. Both found evidence of underinvestment in agricultural research, but the solution of the Fox model indicated that optimal funding for each of the categories of research was on the order of four times the actual level in the late 1970's. The aggregate underinvestment problem was found to be equally serious for each of the four research types. Neither crops nor livestock research or basic nor applied research was found to be relatively more inadequately supported.

IDENTIFYING SOUTHERN PINE FORESTRY RESEARCH PRIORITIES

Background

The southern pine forestry research effort has recently become a focus of attention, due in part to the Southern Timber Study. The USDA Forest Service has brought together the diverse forestry interest groups in the South in an effort to develop an analytical database for formulating and guiding public and private forest policies. It is possible to apply techniques discussed earlier to southern pine forestry to determine research priorities.

The research resource allocation question concerns the choice of funding levels for types of forestry research for essentially a single output. Categories include fire, insect, disease[3], renewable resource evaluation, renewable resource economics, timber management, forest products utilization, forestry engineering and other[4]. The last three categories are predominantly concerned with post-harvest research problems. The focus of this study is on the allocation of research resources for pre-harvest forestry problems.

Congruence Calculations

While congruence ratios possess limited prescriptive power, the approach does give some insight into the intensity of research investment across commodity groups and regions. Tables 4 and 5 document the level of Federal research funding in the South. Volume and value of production are reported in table 6.

[3]*As of 1974, the insect and disease categories were reported as a combined total.*

[4]*Includes cooperative aid, insect and disease control detection and appraisal, range, recreation, requirements and supply, research construction, watershed, wildlife and fish habitat, and miscellaneous.*

Similar tables could be constructed for the other regions in the United States and sets of congruence ratios could be formulated. Comparisons could be made of functional activity categories of research per $1,000 of product value across regions. Using the USDA Forest Service *Wildfire Statistics*, comparisons could be made of the levels of fire prevention and control research relative to the actual incidence of fires across regions.

It should be noted that tables 4 and 5 report Federal research allocations. If it is suspected that State allocations among functional activities vary among regions, similar tables for State expenditures would be necessary to complete the congruence picture.

A Social Surplus Model of Research Resource Allocation

Data on inputs up to the point of harvest are quite limited, which precludes the use of a production function model. It is possible, however, to develop a social surplus model along the lines of those presented earlier. A model of supply and demand are needed. A log-linear version of the demand function could be estimated as

$$\ln Y_t^D = \sigma^D + \eta^D \ln P_t + \eta^I \ln I_t$$

Table 4.--Federal research funds allocated to the Southern Forest Experiment Station by functional activity, 1955-1983

(In current dollars)

Year	Functional activity					
	Fire	Insect	Disease	Renewable resource evaluation	Renewable resource economics	Timber management
1955	8,500	31,200	32,750	105,000	12,000	341,846
1956	8,500	49,624	32,750	105,000	12,000	544,513
1957	36,786	65,000	52,000	136,000	42,100	686,000
1958	38,276	68,058	54,145	176,565	44,956	767,440
1959	38,276	68,054	54,145	176,529	44,956	986,381
1960	40,496	72,613	57,725	185,813	47,916	1,044,830
1961	50,791	88,175	73,133	187,253	48,224	1,161,315
1962	78,091	147,975	152,633	219,903	80,924	1,348,965
1963	78,091	168,975	166,633	217,903	80,924	1,339,965
1964	82,691	205,095	178,233	231,703	86,124	1,538,745
1965	84,070	425,355	215,510	264,640	87,740	1,583,910
1966	85,550	432,605	220,500	270,390	89,800	1,649,790
1967	87,850	472,305	253,500	296,090	99,030	1,683,759
1968	89,900	601,200	268,000	328,600	140,100	1,786,800
1969	91,900	621,200	276,800	339,700	144,800	1,847,400
1970	111,700	639,600	285,300	381,400	151,200	1,924,100
1971	115,700	683,600	331,300	490,400	207,200	2,081,100
1972	123,100	749,700	510,800	536,400	228,100	2,248,200
1973	123,500	888,000	476,200	538,100	228,900	2,770,600
1974	123,500	1,400,200		538,100	228,900	2,347,600
1975	134,100	1,521,100		588,400	252,300	2,669,900
1976	138,300	2,063,400		710,300	265,200	2,671,500
1977	145,900	2,262,200		1,059,000	284,900	2,871,900
1978	152,700	2,371,200		1,445,000	301,300	3,556,100
1979	159,000	2,532,000		1,485,000	313,000	4,211,000
1980	103,000	2,650,000		1,511,000	321,000	4,361,000
1981	174,000	3,607,000		1,716,000	389,000	5,196,000
1982	155,000	3,516,000		1,572,000	394,000	4,621,000
1983		3,506,000		1,673,000	385,000	4,601,000

Table 5.--Federal research funds allocated to the Southeastern Forest Experiment Station by functional activity, 1955-1983

(In current dollars)

Year	Functional activity					
	Fire	Insect	Disease	Renewable resource evaluation	Renewable resource economics	Timber management
1955	25,477	30,714	62,158	90,000	14,500	320,040
1956	25,477	30,714	62,000	90,000	15,000	430,198
1957	40,112	45,000	68,000	120,000	42,000	454,000
1958	132,033	47,908	82,900	164,500	43,500	510,196
1959	202,083	47,909	82,900	164,500	43,500	643,526
1960	213,859	51,731	87,774	173,145	46,374	691,997
1961	214,732	76,917	112,780	173,640	46,651	739,512
1962	275,032	132,417	214,980	202,459	74,051	848,312
1963	278,032	163,066	269,246	200,459	85,701	770,837
1964	294,432	270,265	345,946	213,159	91,101	818,037
1965	299,360	423,880	425,750	240,740	92,800	925,060
1966	458,950	458,770	434,850	247,560	94,450	949,510
1967	459,350	502,270	453,550	283,340	152,920	1,089,641
1968	469,800	514,700	469,400	313,500	162,600	1,169,700
1969	463,800	533,300	486,500	324,800	168,100	1,255,300
1970	479,900	549,500	528,900	356,900	171,600	1,292,300
1971	508,900	586,500	525,900	426,900	181,600	1,406,300
1972	569,600	645,700	575,100	465,800	197,900	1,707,900
1973	1,097,800	648,500	577,200	467,400	198,600	1,720,300
1974	917,800	1,225,700		467,400	198,600	1,791,900
1975	978,500	1,330,700		516,100	184,200	1,971,400
1976	1,122,300	1,907,900		630,200	193,200	2,367,800
1977	1,201,600	2,000,900		973,900	207,000	2,524,000
1978	1,251,100	2,071,200		1,328,300	215,700	3,013,600
1979	1,297,000	2,067,000		1,380,000	222,000	3,188,000
1980	1,364,000	2,103,000		1,430,000	253,000	3,066,000
1981	1,459,000	2,303,000		1,656,000	384,000	3,699,000
1982	1,276,000	1,990,000		1,407,000	330,000	3,285,000
1983	1,257,000	2,179,000		1,614,000	343,000	3,095,000

where Y_t^D is the level of production from table 6, P_t is the stumpage price of table 6 suitably adjusted for inflation, and I_t is a measure of real national income. η^D and η^I are the elasticities of demand with respect to price and income respectively.

Because trees take time to mature and can be harvested at various stages of growth, supply is more difficult to model. Conceptually, we want to relate the level of harvest activity, Y_t^s, to the stumpage price, P_t, and to lagged expenditures of research, R_{t-i}. To reflect the dynamic nature of the production process for wood, a variable which is intended to approximate the stock of wood, S_t, is also included. A constant elasticity log-linear supply schedule could be estimated as

$$Y_t^s = \alpha\left(\prod_{i=0}^{I}\prod_{j=1}^{J} R_{jt-i}^{\beta ij}\right)P_t^{\eta S}\, F_t\,(S_t)$$

R_{jt-i} is the level of research expenditure on functional activity j in time period t − i. There are five relevant categories of functional activities. It is suggested, based on the agricultural research literature, that a quadratic distributed lag with zero-

Table 6.--Volume of southern pine production and stumpage prices, 1950-1981

Year	Production	Stumpage prices
	Million board feet	Nominal dollars per thousand board feet
1950	9,939	26.70
1951	8,495	34.60
1952	8,572	38.50
1953	7,581	34.20
1954	7,332	29.70
1955	7,360	32.00
1956	7,740	37.40
1957	6,568	31.50
1958	6,410	31.10
1959	6,716	35.20
1960	5,660	34.50
1961	5,622	26.80
1962	5,733	26.00
1963	6,055	25.10
1964	6,414	27.80
1965	6,628	31.70
1966	6,609	38.60
1967	6,511	38.30
1968	6,901	42.40
1969	7,181	51.70
1970	7,063	44.10
1971	7,736	52.20
1972	7,884	65.60
1973	7,895	93.40
1974	6,921	76.20
1975	6,967	57.00
1976	7,598	100.30
1977	8,239	134.50
1978	8,267	155.20
1979	8,034	155.40
1980	6,880	172.00
1981 (preliminary)	6,824	127.20

Source: Historical statistics of the United States: colonial times to 1970, U.S. Department of Commerce, Statistical abstract of the United States, various years.

constrained end points be imposed on the β_{ji}'s to economize on requirements for data.

We only have periodic estimates of the stock variable, S_t—that is, the present inventory of standing timber. However, if we assume that the age profile of the annual harvests remains relatively stable, a series for S can be constructed from planting and seeding rates from table 7, from harvested acres and regeneration rates reported by Tansey (1983a, 1983b), and from average yields from table 8. Let $PL_t - i$ represent the average planted, seeded, or naturally regenerated i periods ago. Let Y_t represent the harvest level in period t, and θ_i be the average yield in board feet per area of a stand of timber i years old. The stock variable can be constructed as

Table 7.--Total annual planting and seeding in the Southern Region, 1925-1979

(In acres)

Year	Area	Year	Area
1925	32,038	1951	255,099
1926	6,530	1952	256,624
1927	3,203	1953	431,047
1928	9,857	1954	520,026
1929	13,470	1955	501,746
1930	13,221	1956	601,288
1931	8,460	1957	820,078
1932	8,650	1958	1,110,103
1933	2,770	1959	1,679,944
1934	19,901	1960	1,581,408
1935	45,595	1961	1,211,131
1936	114,342	1962	834,579
1937	118,117	1963	813,306
1938	194,018	1964	777,484
1939	173,391	1965	728,050
1940	178,750	1966	718,039
1941	194,821	1967	782,101
1942	66,213	1968	812,605
1943	19,838	1969	806,477
1944	10,879	1970	876,794
1945	56,782	1971	1,024,545
1946	57,004	1972	1,016,122
1947	57,110	1973	1,052,708
1948	187,708	1974	1,051,246
1949	226,037	1975	1,272,018
1950	294,377	1976	1,195,865
		1977	1,323,618
		1978	1,338,353
		1979	1,370,168

$$S_t = \sum_{i=0}^{t} \theta_i \, PL_{t-i} - \sum_{i=0}^{t} Y_{t-i}$$

In choosing a harvest strategy, owners of forested land consider the current stumpage price, the expected gain in wood volume at some future date, the expected stumpage price at that date, and the opportunity cost of postponing harvest. These factors are embedded in the function $F_t(S_t)$.

Values of θ are only available for 5-year intervals, so an interpolation technique would need to be employed to obtain the full set of θ_i's. Also, the average yields for the four species would need to be collapsed into a weighted average since the model is formulated at an aggregate level of all southern pine output.

Given projected values of national income, I_t, a dynamic cost-benefit model can be used to compute changes in social surplus as a function of research expenditures. The optimal size and composition of the research budget can be computed by choosing levels of the $R_j t$'s that give a discounted present value of the social surplus gains equal to the marginal opportunity cost of public funds[5] for each of the categories of research.

[5]*It should be noted that the marginal opportunity cost of $1 of public funds exceeds $1 (Browning 1976, Stuart 1984).*

Table 8.--Average volume per acre of southern pine species

(In board feet per acre)

Age of stand	Species			
	Loblolly pine (Site Index 90)	Longleaf pine (Site Index 70)	Shortleaf pine (Site Index 70)	Slash pine (Site Index 80)
15	850	200	--	1,500
20	5,000	1,000	250	4,000
25	9,500	3,000	2,800	7,500
30	14,500	5,500	6,900	12,000
35	19,000	8,000	11,750	16,000
40	24,000	10,500	16,400	19,000
45	28,000	13,000	20,250	22,000
50	31,500	16,000	23,800	24,000
55	34,500	18,000	27,000	26,000
60	37,000	20,500	29,700	27,500
65	39,500	22,500	32,000	
70	41,500	24,500	34,100	
75	43,000	26,500	35,900	
80	44,500	28,000	37,700	

Source: Volume, yield and stand tables for seasonal growth of southern pine, U.S. Department of Agriculture, Forest Service, Misc. Publ. 50, August, 1976.

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Fox Glenn.

A framework for identifying public research priorities: an application in forestry research. Gen. Tech. Rep. NC-109. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 21 p.

Discusses attempts to model and measure the relationship between research and development activity and the rate and nature of technological change in recent decades. Reviews efforts to model optimal research resource allocation, and presents a model for southern pine forestry research.

KEY WORDS: Optimal budget allocations, resource allocation, optimal research budgets, optimization procedures, research evaluation.

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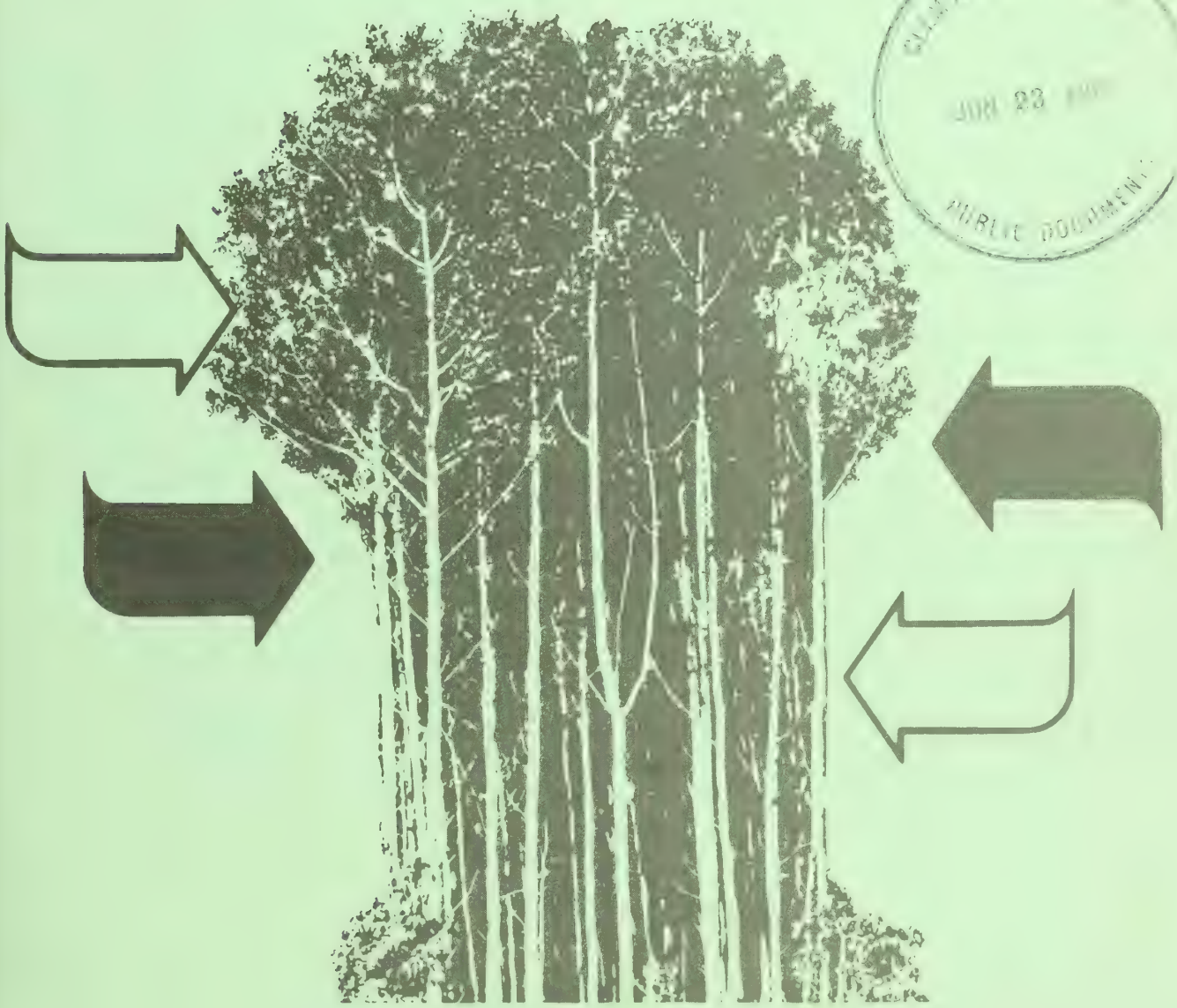
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Alternative Approaches to Forestry Research Evaluation: An Assessment



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ALTERNATIVE APPROACHES TO FORESTRY RESEARCH EVALUATION: AN ASSESSMENT

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and **Earl C. Leatherberry**, *Geographer*,

This publication is based on the Final Report for Project Number 23-81-17, "Assessment of Alternative Approaches to Forestry Research Evaluation," submitted to the North Central Forest Experiment Station in December 1983 by principal investigator Hans Gregersen and research assistants David Bengston, Jim Olmstead, and Robert Westgate (Gregersen *et al.* 1983a).

TABLE OF CONTENTS

	Page
INTRODUCTION	1
AN EVALUATION FRAMEWORK—*Hans Gregersen and Allen Lundgren*	2
RESEARCH EVALUATION: LESSONS FOR FORESTRY	6
Agricultural Research Evaluation—*David N. Bengston*	7
Industrial Research Evaluation—*Jim Olmstead*	13
Other Approaches—*Robert A. Westgate and David N. Bengston*	19
FORESTRY RESEARCH EVALUATION—*Hans Gregersen and Christopher D. Risbrudt*	21
SUMMARY—*Pamela J. Jakes*	25
LITERATURE CITED	27

INTRODUCTION

Forestry research evaluation is a relatively new ıbdiscipline of evaluation research.

Fishel (1981) has identified three uses of evalua-ons: (1) education, (2) resource allocation, and) policymaking. Until recently, most forestry re-arch evaluations have been used primarily for re-urce allocation or policymaking. A recent move ward more quantitative, objective evaluations has sulted in a greater use of these evaluations for lucation.

In forestry research evaluation we deal mainly ith three potential user groups: (1) policymakers egislators or high-level decisionmakers), (2) re-arch administrators, and (3) researchers. These ree user groups parallel those found in other disci-ines. For example, the Commission of the Eu-pean Communities also recognizes three levels of ser groups: policy, managerial, and scientific (Bog-o 1982). Although there are similarities among sers of research evaluations, each evaluation must e tailored to fit the user's particular needs and situ-ion.

This report is basically a review of the field of search evaluation. It begins with an evaluation framework that will facilitate organization of material presented later. This is followed by a discussion of research evaluation approaches from agriculture, industry, and other sectors. Examples of forestry research evaluations are then presented. It concludes with a summary of our findings and recommendations for future research.

Although we have introduced a number of approaches, this is not a cookbook for forestry research evaluation. Rather than providing detailed descriptions of methods, we have offered a framework that can aid the reader in analyzing the methods and case studies discussed. We have focused on the process, the philosophy of designing and choosing an appropriate approach, and the factors to consider in carrying out an evaluation.

The authors of this report have undertaken several major forestry research evaluations; thus, the analyses and recommendations are based on practical experience (Bengston 1984, Westgate 1985, Gregersen *et al*. 1983b). This experience indicates that the real challenge in a research evaluation is to develop an evaluation that blends the real-world constraints of data limitations, uncertainty, and conflicting objectives into a result that is useful.

AN EVALUATION FRAMEWORK

Hans Gregersen[1] and
Allen Lundgren[2]

The problem in conducting this research was not one of finding enough evaluation material, but of digesting, organizing, and synthesizing it to make it relevant and useful for forestry policymakers, research administrators, and other potential users. The framework that follows should help the reader analyze the methods and case histories discussed later. Of many possible frameworks, we know that this one works, and that it will aid the user in developing a useful evaluation approach for a specific problem. It is based on the following steps (fig. 1): (1) Establishing the evaluation objectives, (2) identifying the evaluation measures and criteria, (3) selecting an analytical model, and (4) interpreting and presenting the results. Each element is discussed in detail below.

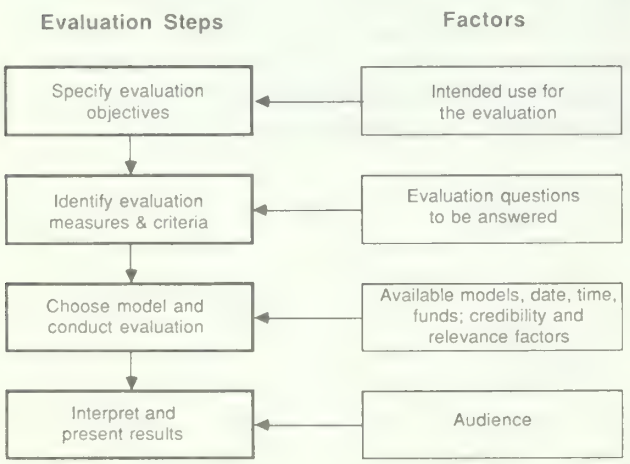


Figure 1.—*A research evaluation framework: critical steps in the evaluation process and factors affecting each step.*

[1]*The author is a Professor, Department of Forest Resources, College of Forestry, University of Minnesota.*

[2]*At the time this chapter was being prepared the author was a Forest Economist, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.*

Establishing the Evaluation Objectives

Evaluations can be undertaken for a variety of reasons and with a variety of objectives—in most cases, one research evaluation can serve a number of objectives. However, when starting out it is important that the evaluator and client agree on the reasons for conducting the evaluation. In addition to the education, resource allocation, and policymaking uses discussed earlier, there may be another consideration: the client's "hidden agenda"—i.e., whether the evaluation will eventually be used in an advocacy or nonadvocacy situation. All considerations must be clear to the evaluator and client.

In addition to the objectives of the evaluation, the objectives of the research must be known, since they help determine relevant evaluation measures. The following research objectives might be encountered in applied forestry research (Fedkiw 1981, Callaham 1981):

- Reduce costs of production.
- Increase quality of goods or service.
- Reduce uncertainty in production or consumption.
- Increase quantity per unit time, resource, etc.
- Increase variety or opportunity access (e.g., new products).
- Prevent loss (maintenance research).
- Increase stability of production or consumption system.
- Redistribute costs or benefits of forestry activities.

Serious problems can arise if research objectives are defined too narrowly, since the evaluator cannot credit to the project benefits from accomplishments not identified in the objectives. The evaluation may indicate that the project was unsuccessful when in fact it was very successful. This point has been discussed by Fasella (1982) as the "Christopher Columbus effect." Columbus set off to find a new route to the Indies and failed; but one could hardly call the mission a failure. Evaluations need to be flexible, with objectives that encompass any byproducts of a research project.

Identifying the Evaluation Measures and Criteria

The next step is to formulate questions to be answered by the evaluation. These questions help determine evaluation methods and criteria. For example, a policymaker asks for information related to the economic efficiency of a project. Because the policymaker's questions deal with economic efficiency, the evaluation must include measures of economic worth. In this case, the evaluation questions can be translated quickly into appropriate evaluation measures.

Evaluators do, of course, ask many noneconomic questions. Patton (1982) has identified 33 sets of questions asked by evaluators (table 1). Only a few of them can be answered by strictly economic evaluations. Noneconomic evaluation questions are less easily associated with specific evaluation criteria and measures. The process of identifying noneconomic criteria and measures illustrates the iterative nature of the evaluation process and the fact that most evaluations involve a series of successive approximations.

Selecting an Analytical Model

Several sources list and describe evaluation techniques, including Porter *et al.* (1980), Schuh and Tollini (1979), and Salasin *et al.* (1980). But before an evaluator becomes immersed in the menu of potential evaluation models, it is important to remember that two actors are involved in choosing the evaluation technique: the evaluator and the client. The evaluator may be primarily concerned with the technical characteristics of the evaluation—data availability, reliability, reproducibility, etc., while the client, or decisionmaker, may be more concerned with relevance and credibility of results. These two main categories—technical considerations and client considerations—are in turn influenced by legal, political, and other constraints. They can be further subdivided as indicated in figure 2, which lays out the main factors affecting the choice of an evaluation approach.

Technical Considerations

Technical considerations focus on (1) constraints imposed by the client or evaluation situation, and (2) individual model characteristics. Constraints are principally dollars, time, and data availability. Four

Table 1.—*Patton's (1982) evaluation question sets*

Question set
Does the program meet minimum standards for accreditation or licensing? (Accreditation evaluation)
What services should clients be receiving? To what extent are current services appropriate to client needs? (Appropriateness evaluation)
Who knows about the programs? What do they know? (Awareness focus)
What is the relationship between program costs and program outcomes (benefits) expressed in dollars? (Cost/benefit analysis)
To what extent has a specific objective been attained at the desired level of attainment (the criterion)? (Cost-effectiveness evaluation)
What information is needed to make a specific decision at a precise point in time? (Decision-focused evaluation)
What happens in the program? (No "why" questions or cause/effect analyses.) (Descriptive evaluation)
To what extent is the program effective in attaining its goals? (Effectiveness evaluation)
Can inputs be reduced and still obtain the same level of output or can greater output be obtained with no increase in inputs? (Efficiency evaluation)
What are the inputs into the program in terms of numbers of personnel, staff/client ratios, and other descriptors of levels of activity and effort in the program? (Effort evaluation)
To what extent is this program able to deal with the total problem? How does the present level of services compare to the needed level of services? (Extensiveness evaluation)
The evaluation is conducted by people outside the program in an effort to increase objectivity. (External evaluation)
How can the program be improved? (Formative evaluation)
To what extent do individual clients attain individual goals on a standardized measurement scale of 1 (low attainment) to 5 (high attainment)? (Goal attainment scaling evaluation)
To what extent have program goals been attained? (Goals-based evaluation)
What are the actual effects of the program on clients (without regard to what staff say they want to accomplish?) (Goal-free evaluation)
What are the direct and indirect program effects on the larger community of which it is a part? (Impact evaluation)

(Table 1 continued)

Table 1.—Continued

Question set
Program staff conduct the evaluation. (Internal evaluation)
What happens to the program and to participants over time? (Longitudinal evaluation)
Was the evaluation well done? Is it worth using? (Meta-evaluation)
What do clients need and how can those needs be met? (Needs assessment)
How does this program population compare to some specific norm or reference group on selected variables? (Norm-referenced evaluation)
To what extent are desired client outcomes being attained? What are the effects of the program on clients? (Outcomes evaluation)
What are participants actually able to do as a result of participation in the program? (Performance evaluation)
How effective are staff in carrying out their assigned tasks and in accomplishing their individual goals? (Personnel evaluation)
What are the strengths and weaknesses of day-to-day operations? How are program processes perceived by staff, clients, and others? What are the basic program processes? How can these processes be improved? (Process evaluation)
What are the characteristics of specific and concrete products produced by or used in a program? What are the costs, benefits, and effects of those products? (Product evaluation)
Are minimum and accepted standards of care being routinely and systematically provided to patients and clients? How can quality of care be monitored and demonstrated? (Quality assurance)
What routine social and economic data should be monitored to assess the impacts of this program (e.g., health statistics, housing statistics, employment statistics)? (Social indicators)
Should the program be continued? If so, at what level? (Summative evaluation)
What information is needed and wanted by decisionmakers, information users, and stakeholders that will actually be used for program improvement and to make decisions about the program? (Utilization-focused evaluation)

characteristics of each model or technique are particularly important in the selection process: (1) reliability, (2) relevance, (3) relative cost, and (4) data requirements.

Reliability is determined by the theoretical soundness of the model, reproducibility of the results, objectivity, and acceptance by the scientific community. Model relevance is concerned with two factors: the extent to which the approach can generate results by the time they are needed, and the extent to which the model provides answers to the evaluation questions. Relative cost is the cost of using the model in relation to the available budget.

The question of data needs and availability is a critical one. Models differ dramatically in data needs. In the case of forestry, models that depend heavily on production and growth time series data, which are generally unavailable, may have to be discarded. Schuh and Tollini (1979) concludes that, ". . .simple approaches which are less demanding in terms of data are more useful than more complicated procedures which have to be based on more precarious data."

Client Considerations

As discussed earlier, the major impact of the client on the evaluation process is in determining objectives. We've discussed the three uses of research evaluation: (1) resource allocation, (2) policymaking, and (3) education. The evaluation technique is also affected by whether the evaluation will be used in an advocacy or nonadvocacy situation.

Another major consideration is the client's criteria for use. Although the relevance of the evaluation is important in determining whether an evaluation is used, some would argue that the overriding consideration is credibility. A 1976 report of the House Subcommittee on Oversight and Investigations states that the most significant factor in the acceptance of a benefit-cost study is the name of the sponsor (Anonymous 1980). Thus, the question of credibility is critical.

Credibility is influenced by four factors:

1. The perceived independence of the evaluator. For example, the research evaluation program of the Commission of the European Communities (CEC), stressed that "the independence of the assessments was considered essential to ensure objectivity and so to provide credibility" (Contzen *et al*. 1982).
2. The understandability of the evaluation approach.
3. The consistency of the evaluation results with other evaluations. However, too many favorable evaluations, with no negative ones, can decrease credibility.
4. The degree of agreement with the decisionmaker's intuitive judgment and beliefs. Along similar lines, the more the approach and results are accepted by the decisionmaker's trusted advisors or analysts, the more credible the evaluation.

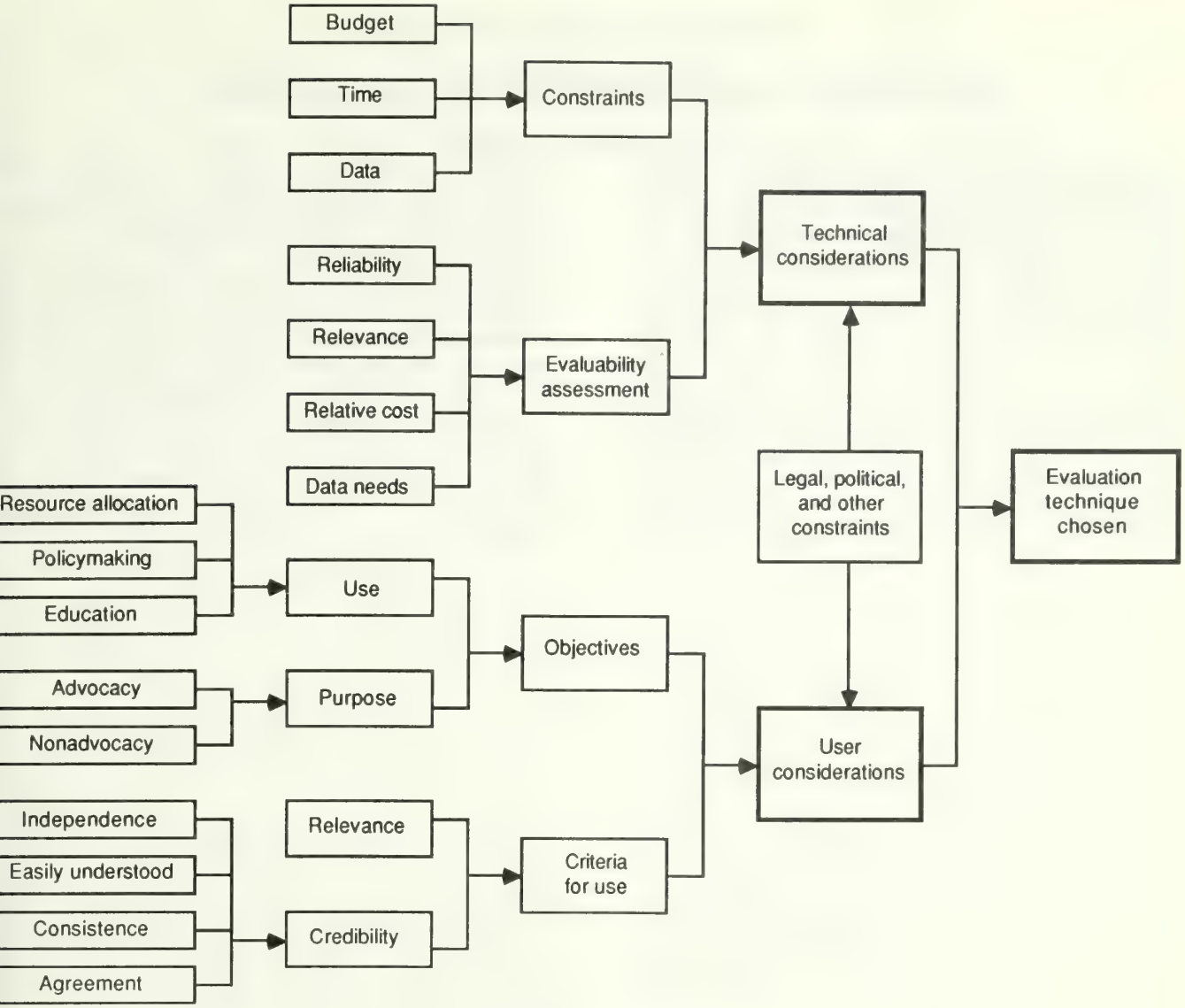


Figure 2.—*Factors affecting the choice of an evaluation approach.*

Interpreting and Presenting the Results

Results of evaluations are often misinterpreted. Correct interpretations depend on good evaluations—i.e., those which consider the relevant dimensions of the situation. For example, the fact that a number of isolated research evaluations turn up with quite high rates of return to research does not mean that there is a general underinvestment of funds in this field of research. One can infer nothing about overall program funding from a review of a few isolated project evaluations. Further, most evaluations measure a very specific impact of a project along one narrow dimension (e.g., economic efficiency). One has to be careful not to broaden the interpretation to include dimensions not covered by the model.

RESEARCH EVALUATION: LESSONS FOR FORESTRY

Forestry research evaluators need not operate in a vacuum; there is a large body of literature in agricultural and industrial research evaluation, among other areas, to which they can turn for guidance. By studying examples from other fields, we can assess the potential usefulness of the various approaches or combinations of approaches for forestry research evaluation.

The point about combinations of approaches bears some emphasis. In most forestry research situations, some combination of quantitative and qualitative evaluation tools is needed, especially in research areas not dealing directly with market-priced products. As will be discussed later, 75 percent of agricultural research evaluations deal with a narrow range of commercial field crops. There are relatively few examples of quantitative evaluations that address other types of agricultural research.

This chapter, which covers a wide array of approaches to research evaluation, is arranged in three sections. It begins with a review of agricultural research evaluation, where efforts have focused heavily on methodology. This is followed by a review of industrial research evaluation, where the approach has been much more pragmatic. The final section of the chapter discusses other approaches to research evaluation not readily placed in disciplinary categories.

AGRICULTURAL RESEARCH EVALUATION

David N. Bengston[3]

A substantial amount of research has been done on the economic evaluation of agricultural research and extension (R&E). Four major symposia have been held in the United States and one in Canada to discuss various aspects of "research on research" (Fishel 1971, Norton *et al.* 1981, Davidson 1973, Arndt *et al.* 1977). Agricultural research evaluation has provided guidance and focus for research on forestry research evaluation. The primary objective of agricultural research evaluations has been development of methodology or, if we follow Fishel's breakdown, education. Approaches have been developed to evaluate returns to investments in agricultural R&E, to investigate other effects of research, and to efficiently allocate research resources. These techniques have been applied in scores of studies on several types of research at various levels of aggregation. In addition to the many empirical studies, the literature abounds with critiques of existing evaluation methodologies and theoretical investigations aimed at extending or refining current approaches.

The approaches developed to assess the economic impacts of investments in agricultural R&E range from simple scoring models to sophisticated production function analyses. Following Schuh and Tollini (1979), these methodologies are divided into two main categories: *ex post* techniques (which attempt to evaluate past research) and *ex ante* techniques (which attempt to evaluate proposed research projects or programs). The major methodologies that fall into these categories are as follows:

Ex post

a. Consumer and producer surplus
b. Production function
c. Allocative efficiency
d. Public relations

Ex ante

a. *Ex ante* benefit-cost
b. Simulation models
c. Mathematical programming
d. Scoring models

[3]*At the time of this research, the author was a graduate assistant, Department of Agricultural and Applied Economics, University of Minnesota.*

Each evaluation approach has unique characteristics that determine its suitability for a specific situation. Five of the methods yield rates of return to R&E investments: consumer and producer surplus, allocative efficiency, *ex ante* benefit-cost, production function, and simulation models. Mathematical programming and scoring models are intended to be used in allocating resources. They provide a ranking of projects or determine an optimal mix of research activities. The "public relations" approach (Peterson 1969), while not a formal evaluation technique, is included in this section because of its long history of use.

Other informal research evaluation methods are routinely used by research decisionmakers. For example, the professional reputation of a researcher is a frequently used criterion for allocating research funds at the project level: "Probably the best predictor of the outcome of an individual project is the recent 'track record' of the scientist proposing it" (Peterson 1978). These types of evaluation methods will not be considered here, although they probably figure prominently in research management decisionmaking (Gold 1969). Since the contribution of agricultural research evaluation to forestry has been primarily methodological, we will focus on methods rather than case studies.

Ex Post Methods

Consumer and Producer Surplus

Of the agricultural R&E evaluation methods which yield rates of return, the consumer and producer surplus (or index number) approach has the longest history of use. The seminal work of Schultz (1953), Griliches (1958), and Peterson (1966) employed this technique, and it has been widely used and further refined in subsequent studies.

The basic idea in this approach is that the adoption of technological innovations resulting from research reduces the marginal cost of producing the commodity in question, and this in turn increases the amount produced and lowers the market price (fig. 3). In the figure, the shift in aggregate supply

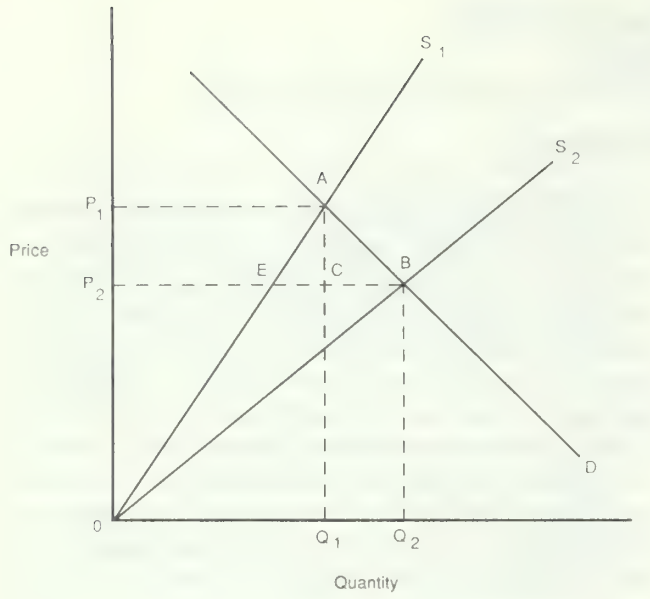


Figure 3.—*Generalized conceptual framework for the evaluation of research benefits using the consumer and producer surplus approach.*

from S_1 to S_2 causes a change in consumer surplus, represented by the area P_1 ABP_2. Producer surplus is the area EOB minus P_1 AEP_2. Producer plus consumer surplus is the total change in economic surplus, which is equal to the area AOB.

Although a good deal of theoretical controversy surrounds the concept of economic surplus, the analysis of consumer and producer surplus by practitioners is widespread.

Production Function

The use of the production function technique to analyze the effects of research on agricultural production dates back to early studies by Tang (1963), Griliches (1964), Latimer (1964), and Peterson (1967). The idea underlying this evaluation approach is that research can produce an increase in the quantity of a good produced with a fixed amount of traditional inputs. Another way of saying this is that research causes the production function to shift upward. The contribution of research to productivity growth is assessed by fitting a production function (usually a Cobb-Douglas specification) with research as an independent variable. Regression analysis makes it possible to isolate the effects of research on production, while at the same time controlling for the use of other inputs that have an impact on productivity.

Since research conducted in a given year does not have an immediate impact on productivity, a time lag for the impact of expenditures on output must also be specified. Evenson (1967) has shown that an inverted V-shaped distribution with a mean lag of 6 1/2 to 7 years is most appropriate for production-oriented agricultural research.

Proper specification of the research or the R&E variable is vitally important in this evaluation method. Three main approaches have been used in specifying the research variable: the annual expenditure on research, the level of adoption of an innovation resulting from research, and number of research publications. Griliches (1964) was the first to use the annual expenditure on research, and it has been adopted in most other production function research evaluations. Even though data availability makes this approach appealing, using some measure of research output (which is an input of the production process) would be more correct than using research expenditures (which is an input of the research process). Measuring research output can be problematic in many cases, however, so the assumption is made that research expenditures represent a good proxy for research output.

Another method of specifying the research variable is to use a measure of the adoption of a technological innovation resulting from research. For example, Sim and Araji (1980) used the acreage harvested of wheat varieties bred by the Western Agricultural Experiment Station system as a measure of research output. Specifying the variable in this manner is theoretically more sound, but it limits the evaluation to types of research for which the output is easily measured.

The third specification is to use the number of publications in scientific journals resulting from publicly funded research as a proxy for research output. However, this ignores the question of actual adoption. See Evenson (1974) for an example of this approach.

Allocative Efficiency

Allocative efficiency, or the adjustment to disequilibrium approach, has been used by Huffman (1974, 1977) to estimate the value of improved information resulting from agricultural extension. In Huffman's model, extension contributes to allocative efficiency by speeding up the rate of adjustment to disequilibria in the use of nitrogen fertilizer. An adjustment equation is specified in which changes in the use of variable inputs to optimal levels are related to extension:

> The novelty of the model is that the adjustment coefficient is specified as a

vector of environmental variables, including extension. The variable adjustment specification of the dynamic model permits a test of the hypothesis that agricultural extension enhances adjustment to changes in economic incentives, which is one aspect of allocative efficiency. Closing the disequilibrium gap increases farm profit (Huffman 1978).

The allocative efficiency approach is capable of nalyzing the adoption of new inputs or technology roduced by research, although it apparently has not een used for these purposes. It also holds some romise for evaluating the returns to some types of ocial science research for which improved informaon is the main output of the research effort. Data equirements for this evaluation approach are modrately heavy. Huffman's model requires data on anticipated farm input and output prices, fixed and ariable input use, and environmental variables afcting input use, including extension.

ublic Relations

The "public relations" approach (Peterson 1969) as been used more widely than any other research valuation method. It usually consists of a nontechical description of what the outcome of a research ffort has been, or what the expected outcome will e. This approach is used most often for *ex post* evalations, but it can also be used for *ex ante*. Some ublic relations evaluations include quantification benefits from a research effort, but no attempt is ade to determine whether benefits exceeded costs.

Advantages of this approach include its low cost, mplete flexibility, and accessibility to the general ublic. The main disadvantages are that it gives no nformation to help allocate research resources more fficiently, and it gives a somewhat inaccurate view the research process by making it appear that roducers are the main beneficiaries of agricultural esearch and that virtually all research is successful. ee Fletcher (1937) and Salisbury *et al*. (1973) for xamples of the public relations approach.

Ex Ante Methods

x Ante *Benefit-cost*

The use of *ex ante* benefit-cost analysis for evaluatng agricultural research is a relatively recent develpment. Fishel (1971) designed a model which calcuates benefit-cost ratios and internal rates of return to proposed research projects. This model is "a computer-based, generalized structure for collecting and processing information relevant to resource allocation decisions under situations characterized by a high degree of uncertainty" (Fishel 1971). Other *ex ante* benefit-cost research evaluations have been much simpler, usually focusing on single research projects (Araji and Sparks 1975) or commodity-specific research programs (Araji *et al*. 1978, Barker 1981).

This evaluation method is conceptually analogous to the consumer and producer surplus approach. The main difference is that in an *ex ante* benefit-cost study the effects of research on productivity (and hence on consumer and producer surplus) are estimated and projected into the future rather than being observed from past data. These projections are most frequently obtained from interviews or questionnaires given to research scientists. The scientists are asked to give their subjective judgments about such questions as the expected time requirements for a research project, probability of success, size of benefits, rate of adoption of results, and costs of conducting the research. This information is then used to calculate benefit-cost ratios and internal rates of return for current and prospective research projects.

One obvious criticism of this methodology is that it relies heavily on subjective estimates provided by scientists about the costs and expected success of their research, which would likely be biased upwards. Postmortems of *ex ante* evaluations of industrial research proposals reveal that actual costs and returns often vary considerably from what was predicted (Carter and Williams 1958, Marshall and Meckling 1962, Gold 1964).

Castro and Schuh (1977) avoided this problem by using secondary data to estimate projected impacts and costs of agricultural research in Brazil. This study was also unique in that it concentrated on the growth and distributional effects of research rather than on rates of return.

Simulation Models

Simulation models are to the research evaluator what pilot models or experiments are to a natural scientist. An engineer builds a prototype of a machine to see how it behaves. Similarly, a research evaluator constructs a mathematical model to capture the salient features of the research process to assess its behavior.

In a typical evaluation simulation model, changes in productivity are attributed to lagged values of

public investments in research and to other factors thought to influence productivity. The coefficients used for the variables in the model usually come from production function studies.

Fishel's computerized *ex ante* benefit-cost model, which could also be considered a simulation model, was the first application of this technique to the evaluation of agricultural research. Other simulation models used for this purpose have only appeared in the past 8 or 9 years (Pinstrup-Andersen and Franklin 1977, Lu *et al*. 1978, White *et al*. 1978).

The same basic criticism leveled at the *ex ante* benefit-cost approach is applicable to the simulation approach. Subjective estimates of variables such as research time requirements, costs, probability of success, and probability of adoption of results must be fed into the model. The validity of the output of a simulation model will depend on the accuracy of these estimates. Additional data requirements of this approach are highly variable, depending on what questions are of interest. If the effects of research on such concerns as the environment, employment, nutrition, economic policy, trade, or income distribution are important, a great deal of additional data must be incorporated into a simulation model.

Mathematical Programming

Mathematical programming has been used to a very limited extent in agricultural research evaluation to investigate the optimal allocation of research funds. This approach requires an explicit elicitation of the decisionmaker's goals and preference function, which comes at a relatively high cost in terms of a research administrator's time. Given this information and estimates of expected costs and benefits of the research program or project, the output describes the utility-maximizing allocation of the research budget.

There have been only two attempts to apply this methodology to agricultural research evaluation. Cartwright (1971) designed a model to determine the optimal allocation of resources in agricultural economics research in a university department. This model has never been put into practice and remains in the conceptual stage of development. Russell (1977) developed a mathematical programming model to determine an optimal portfolio of publicly funded agricultural research projects. Russell's model was applied to several research programs in Scotland with satisfactory results.

Scoring Models

Scoring models provide a ranking of alternative research projects or problem areas. Shumway defines this approach as one "which formally incorporates the decisionmaker's subjective trade-offs and decision criteria into the model framework" (Shumway 1973). He also provides an excellent review of ranking and scoring approaches used in industrial and agricultural research. This technique is useful primarily as a research management tool: It provides a basis for allocating research resources at various levels.

One of the first applications of the scoring model approach to agricultural and forestry research was done under the aegis of the National Association of State Universities and Land Grant Colleges and the U.S. Department of Agriculture in 1966. This study used a scoring model to arrive at "estimates of socially desirable levels of publicly funded agricultural research in 1972 and 1977 in each of 91 problem areas" (Williamson 1971). The research classification system that was developed in this study is now being used in the Current Research Information System (CRIS) of the U.S. Department of Agriculture.

Other scoring models have been developed to evaluate agricultural research, each addressing slightly different aspects of the problems involved in selecting an optimal research portfolio (Mahlstede 1971, Shumway and McCraken 1975). Some use simple procedures, while others use more complicated techniques to determine rankings, such as the Delphi approach. Data requirements are therefore highly variable, ranging from individual qualitative assessments of the expected benefits and costs of alternative projects to extensive group-determined estimates of project costs, benefits, weights attached to various research goals, etc. Most of the models require large inputs of expensive labor (scientists are usually the evaluators of the research projects). Scoring models are subject to the same criticism as all *ex ante* approaches: The biased opinions of people with a vested interest in the outcome are central to the evaluation.

Limitations of Agricultural Research Evaluation[4]

The sheer number of agricultural research evaluations is impressive—I have identified 85 studies

[4]*For a more detailed discussion of the topic see Bengston (1985).*

Bengston 1985b). Despite the large number, two valuation techniques have been overwhelmingly avored by researchers—the consumer and producer urplus and production function approaches account or nearly three-quarters of all evaluations.

The preponderance of these two approaches is due o several factors. First, since these methods were sed in the first economic evaluations of agricultural esearch, they have undergone more development nd refinement than other techniques. Second, both f these approaches are based on theoretical founda- ions and methods of economic analysis that have een applied (if not universally accepted) for a long me. Finally, there is a common perception among esearch evaluators that the information generated y these approaches is robust (Arndt and Ruttan 977) and the type of information produced is rele- ant to research decisionmakers.

In agricultural research evaluation, crop produc- on research is by far the dominant category. Ani- al production research has received very little cov- rage, even though significant shares of State gricultural Experiment Station research budgets re oriented towards livestock. Most studies not re- ted to production evaluate returns to agricultural xtension, not research.

Why is it that research evaluators have focused on roduction-oriented research so heavily? A main eason is that the outputs are easier to measure than hose from other types of research. For example, re- earch results that produce higher product yields are ore easily measured in economic terms than re- earch results in the form of information, a main utput of social science research.

Evaluation of research on most major agricultural ommodities has been reasonably complete, while overage of less important products has been scat- ered. The small number of evaluations of mechani- al innovations is somewhat surprising in light of he key role that advances in agricultural mecha- ization have played in the productivity growth of merican agriculture (Hayami and Ruttan 1971). A kely explanation is that the bulk of research on echanical agricultural technology takes place in he private sector, and the evaluation literature is lmost exclusively concerned with public sector re- earch.

There has been only one evaluation of a "service roduct" other than the returns to extension studies. Hayami and Peterson (1972) examined the returns o public information services—the statistical re- orting of agricultural commodities. Several evalua- tions of research on intermediate agricultural production processes have been carried out. For example, Araji and Sparks (1975) looked at potato storage research, and Duncan (1972) evaluated pasture improvement research.

Finally, the extent of coverage of agricultural research evaluations may be judged by the objectives of the research that has been evaluated. If we accept that the overall goal of all applied research is improvement in human welfare, this can be broken down into four basic objectives:

1. To improve economic *efficiency in production*—i.e., produce the same output with fewer resources, or more output with given resources.
2. To improve *efficiency in consumption*—i.e., use something longer or get the same utility by consuming less of some good or service, etc.
3. To improve the *quality* of goods or services in final consumption.
4. To "improve" the *distribution of benefits* from consumption or the *distribution of costs* of production.

It should be stressed that improvement in quality as a goal of research must be determined at the final consumption level to be meaningful. Without this distinction the difference between improvement in efficiency of production and improvement in quality becomes blurred.

Using these four objectives to classify the agricultural research that has been covered in the evaluation literature, it is clear that efficiency in production is the primary or sole objective of nearly all the research evaluated. This is not particularly surprising, since crop and animal production have been the dominant types of research looked at. But even among the nonproduction studies there have been very few evaluations of research with objectives other than efficiency in production. This is undoubtedly due to the difficult methodological problems encountered in evaluating certain types of research.

The body of literature employing the techniques of agricultural research evaluation is large. For a variety of reasons, application of these techniques has centered on crop production research, and the consumer surplus and production function approaches have been heavily favored. In light of the experience in agriculture, application of existing evaluation methods to forestry research will likely be governed by two main factors: data availability and problems in quantifying the value of forestry research outputs.

Data problems are endemic to the process of evaluating research from an economic perspective. But

difficulties in obtaining the data required to evaluate forestry research will be greater than in the case of agriculture. Data on farm inputs, acres of individual crops harvested, etc. are routinely collected and reported in various State and Federal publications in the U.S. In addition, fairly reliable estimates of economic parameters such as the price elasticities of supply and demand are available for many agricultural commodities. Because this is not the case in forestry, evaluation techniques with heavy data requirements, such as the production function and allocative efficiency approaches, are unlikely to find widespread applicability.

Evaluation methods with relatively low data requirements are more promising in forestry. These include the consumer surplus approach and the *ex ante* benefit-cost and scoring model approaches. Simulation models are also a possibility, since data requirements vary considerably depending on the exact nature of the model that is developed. Other possibilities include hybrid models incorporating elements of existing evaluation methods designed to address the unique aspects of forestry research.

The application of economic evaluation methods will likely be limited for the near future to forestry research that produces outputs easily measured in economic or monetary terms. This is the case in the agricultural literature, where studies of production-oriented research dominate and studies of research results involving nonmarket, nonpriced outputs are almost nonexistent. The forestry literature to date has concentrated on forest products and utilization research, where research outputs are more easily quantified economically than in other areas.

Some economists are working on ways to evaluate other types of research, such as social science research (Norton and Schuh 1981), but these efforts currently remain in the conceptual stage. Until basic advances are made in the tools available to measure the economic impacts of research, forestry research evaluation is likely to concentrate on research that increases technical efficiency in production, such as product utilization and genetic improvement research. Research that results in increased allocative efficiency—such as forest management research—might also be amenable to economic evaluation. In conclusion, an understanding of what has been done in the evaluation of agricultural research and a clear recognition of its limitations are essential prerequisites to finding appropriate and usable evaluation methods for forestry research.

INDUSTRIAL RESEARCH EVALUATION

Jim Olmstead[5]

While agricultural research evaluations have focused both on methodology and its application, industrial research evaluations have been confined primarily to studies of methodology, with few case studies or examples of its application. Also, the methodology developed strongly reflects the real-world constraints of conducting research within organizations trying to exist in a competitive market economy.

American firms spend billions of dollars each year on research and development (R&D). Rettig *et al.* (1975) explains that firms are willing to make this investment because R&D helps meet the firms' objectives of:

1. Providing a steady if not increasing flow of profits.
2. Maintaining competitive positions in present areas of business activity.
3. Improving existing market positions.
4. Entering new markets.
5. Ensuring continued existence of the corporate entity.

R&D accomplishes this by providing:

1. Useful outputs such as process improvements, improvements in the quality of existing products, and new products.
2. Staff that can aid other groups within the firm and serve as the firm's technological intelligence unit.
3. A progressive image for the firm.

Although the relationships between R&D and the firm are easily understood, conceptualizing the relationships in a manner conducive to analysis and planning is an elusive task. As an article in a recent *Harvard Business Review* states:

> "One of the most difficult corporate functions to analyze and assess is research and development. Partly for this reason, few corporate relationships are more consistently troubled than that between R&D and general management . . . the problem is clearly in communication . . . one reason is a failure on the part of general management and research management to agree on what the R&D process is" (Merten and Ryv 1983).

The bottom line for research and development can only be determined within the context of the firm. The results of R&D, in and of themselves, are unlikely to earn much for the firm; rather, profits occur when an innovation is transferred from the laboratory to the marketplace. This activity involves a host of actors and actions. The process is well illustrated by Merrifield (1976) with his concept of the "R&D pipeline"—costs for bringing an innovation to market are incurred at various locations in the firm, not exclusively in the research and development laboratory. Horesh and Kamin (1983) support this concept with their finding that the cost of R&D is only approximately 50 percent of the cost of bringing an innovation to the market.

Mansfield (1982) has determined that on average the probability of an R&D project resulting in an economically successful product or process is 12 percent. This probability takes into account the potential technical and commercial risks. The likelihood of a project being a technical success from the laboratory standpoint is much higher—one survey puts it at 50 percent. However, the commercial risk (the possibility that a new product or process will not merit commercial introduction or application, or that if it does it will not be an economic success) is often much higher.

The preceding discussion has shown that the bottom line for R&D depends as much or more on commercial considerations as technical considerations, and that the actual R&D costs are but a part of the total costs of a marketable innovation. For these reasons the financial evaluation of R&D begins to take the shape of venture analysis. According to Cangemi and Weil (1982), R&D management is moving toward a more systematic, holistic approach, with R&D considered in the context of the firm.

[5]*At the time of this research, the author was a graduate research assistant, Department of Forest Resources, College of Forestry, University of Minnesota.*

Evaluation in Theory

The literature on industrial R&D evaluation deals overwhelmingly with techniques in theory, as opposed to techniques in practice. The techniques, which concentrate almost exclusively on project or problem selection, include front-end analysis, formative evaluations, impact evaluations, and program monitoring.

Hundreds of methods for selecting R&D projects have been put forth in the past 30 years or so. As a result, literature reviews have been numerous; some examples include Baker and Pound (1964), Cetron *et al*. (1967), Moore and Baker (1969), Souder (1972a, 1972b), Augood (1973), Baker (1974), Clarke (1974), Albala (1975), Baker and Freeland (1975), Rettig *et al*. (1975), and Gibson (1980).

As might be expected, there is little agreement among reviewers on how to categorize the many methods of project selection. One format, moving from less to more complex, is as follows:

1. Checklists and profiles.
2. Ranking methods.
3. Scoring methods.
4. Profitability indices.
5. Optimization models.
6. Risk and decision analysis.
7. Staged approaches.

Checklists

In a checklist model, projects are subjectively rated against a simple list of criteria chosen for their significance in achieving project success. The rating of each criterion is indicated by a descriptor such as acceptable or unacceptable. Profiles are basically the same as checklists except that the results are displayed graphically.

Although checklists and profiles are simple, problems may arise in the selection of decision criteria (Augood 1973). Nevertheless, checklists and profiles have achieved some acceptance in the chemical process industry, where users feel that such methods introduce a desired level of formality without demanding more data and specification than are readily available (Souder 1978).

Rankings

In a ranking model, the decisionmaker simply compares projects with one another (Clarke 1974). An example is the Q-sort method, described by Souder (1978) as the simplest and most effective process for ranking a set of R&D projects. The method includes the following steps:

1. Each decisionmaker is given a deck of cards each bearing the name of one project. Cards are sorted according to some specified criterion.
2. The deck is then divided into two piles; one high level, one low level, based on the criterion.
3. Cards from each of the two piles are selected to form a medium-level pile. There are now three piles.
4. Cards from the high-level pile and low-level pile are next divided into two piles each: very high and high, and very low and low. There are now five piles.
5. Finally, the selections are surveyed and rearranged if needed.

Gibson (1980) identifies one disadvantage of ranking models as that they do not require decisionmakers to reveal the bases of their judgments. Experienced managers, however, often feel that they "know" more about their areas of responsibility than they can articulate. Critics also argue that ranking models do not exclude irrelevant and emotional items and do not force considerations of all rational factors. However, managers skilled in management politics do not see this as a problem. Finally, Gibson notes that the most telling argument against ranking models is the lack of reproducibility from manager to manager. Thus, rankings are very personal and could hinder rather than help the decisionmaking process.

Scoring Methods

Scoring methods (also referred to as rating methods) compute an overall project score based on ratings assigned to relevant decision criteria for each project. The higher the score, the more desirable the project. Albala (1975) points out that scoring methods may differ in: (1) the degree of detail or number of decision criteria, (2) whether the numerical values assigned are weighted or unweighted, and (3) whether the numerical values are based on qualitative descriptors (e.g., outstanding = 0.1, very good = 0.8), quantitative descriptors (e.g., annual sales potential less than $25,000 = 1, between $25,000 and $100,000 = 2, etc.), or both.

Scoring methods force both criteria and weightings into the open. Gibson (1980) feels scoring methods are superior to ranking methods, but points out that managers may try to beat the system by writing proposals to fit the scoring methods. Analysts may attempt to thwart such attempts by designing more

complex systems, but the merit of simplicity is then lost.

Profitability Indices

Many methods center on economic or profitability criteria. In general, such indices try to consolidate into a single value the various quantitative elements normally found in conventional economic evaluations. Most of the methods use probability ratios (expected profits to expected costs). They may also include probability of success or risk factors, and costs may be limited to R&D expenses or include full commercialization costs. One of the earliest and often-cited economic indices is that of Olsen (1955):

$$\text{Value of new project} = (IR)(Pt)$$

where:

IR = Value of process savings for 1 year, or 3 percent of new product sales for 5 years, or 2 percent of sales value of improved products for 2 years, depending on the criterion of the organization, and

Pt = Probability of technical success.

Optimization Models

Constrained optimization models seek to optimize some economic function subject to specified resource constraints. They employ some form of mathematical programming, such as linear, nonlinear, integer, or dynamic. Souder (1972a) has presented a bibliography of many such models. Although there are a number of optimization models available, there is no evidence that they have been used by managers (Gibson 1980).

Risk Analysis

Risk and decision analysis models are based on the concept that rational decisionmakers will select those projects having the highest expected value scores (Souder 1978). It requires that each possible outcome, along with its probability and value to the decisionmaker, be established in advance. Risk analysis is typically based on a simulation analysis of input data in distribution form and provides output distributions of such factors as rate of return and market share (Moore and Baker 1969) (fig. 4).

The most likely level of lifetime profits for Project 2 is greater than for Project 1 ($150 million vs. $100 million); so some managers would select Project 2 without further analysis. However, if a manager considers the risks inherent in both projects, she/he may make a different decision. Project 2 has a 0.10 probability of earning no profits and only a 0.40 probability of earning its most likely level, while Project 1 will always earn some profit and has a 0.80 probability of earning its most likely level. While the gambler may stick with the original selection of Project 2, the risk averter would be inclined to choose Project 1.

Decision theory models are attractive because they help to clarify the available strategies and the potential risks, regrets, and tradeoffs, and they are based, at least in part, on a management or policy oriented thought process. There is little evidence that they are put into practice.

Staged Approach

At least three authors (Albala 1975, Souder 1978, Gibson 1980) have advocated an eclectic approach to project selection which attempts to match the selection tool to the characteristics of the decision situation at hand. Known as a staged approach, it is based on two key considerations: the "real-world" aspects of decisionmaking and the changing nature of risks and costs as projects move closer and closer to commercialization. Souder (1978) has contrasted the "real-world" with the idealized view of decisionmaking. (See next page.)

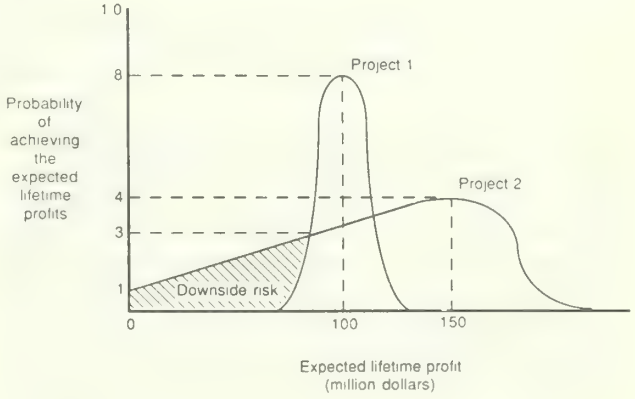


Figure 4.—*An example of risk analysis (Souder 1978).*

Idealized World	Real World
1. A single decisionmaker, in a well-behaved environment.	1. Many decisionmakers and many decision influencers, in an dynamic organizational environment.
2. Perfect information about candidate projects and their characteristics; outputs, values and risks of candidates known and quantifiable.	2. Imperfect information about candidate projects and their characteristics; outputs and values of projects are difficult to specify; uncertainty accompanies all estimates.
3. Well-known, invariant goals.	3. Ever-changing, fuzzy goals.
4. Decisionmaking information is concentrated in the hands of the decisionmaker, so that he has all the information he needs to make a decision.	4. Decisionmaking information is highly splintered and scattered piecemeal throughout the organiziation having all the information needed for decisionmaking.
5. The decisionmaker is able to articulate all consequences.	5. The decisionmaker is often unable or unwilling to state outcomes and consequences.
6. Candidate projects are viewed as independent entities, to be individually evaluated on their own merits.	6. Candidate projects are often technically and eoncomically interdependent.
7. A single objective, usually expected value maximization or profit maximization, is assumed and the constraints are primarily budgetary in nature.	7. There are sometimes conflicting multiple objectives and multiple constraints, and these are often noneconomic in nature.
8. The best portfolio of projects is determined on economic grounds.	8. Satisfactory portfolios may posses many noneconomic characteristics.
9. The budget is "optimized" in a single decision.	9. An iterative, recycling budget determination process is used.
10. One single, economically "best," overall decision is sought.	10. What seems to be the "best" decision for the total organization may not be seen as best by each department or party, so that many conflicts may arise.

Evaluation in Practice

Compared with the literature on theories or models for project selection, the literature on the practice of project selection is scanty. Dean (1968) and Gee (1971) have reported on surveys of project selection practices in the United States, and Allen (1970) on practices in Great Britain. Additional information can be found in occasional reports on practices employed at individual firms, such as Wolff's (1980) study of project selection at Uniroyal. Further, scattered comments appear in the R&D management literature.

In writing about selection practices, researchers have focused more on criteria and people involved than on analytic tools; in fact, descriptions of methods are almost nonexistent. Porter (1978) found that the same methods used for project selection are used for postevaluation. The methods involve calculating a probable returns ratio of profits to R&D costs. Uniroyal uses a scoring model that considers the probabilities of technical and commercial success and the organizational resources required to commercialize the project (Wolff 1980). Finally, the British survey mentioned earlier reported that of their 112 respondents (Allen 1970):

- Ninety-six used net present value, payback period, or average rate of return on capital invested when assessing the commercial viability of projects.
- Ninety-nine estimated the probability of commercial success, technical feasibility, and probable development costs as part of their project evaluation procedure.

- One-third used either mathematical models, weighted checklists, or project ranking procedures as part of their project assessment procedure.
- Twelve had a numerical weighting system on their standard evaluation forms which could be used to form a picture of the weak and strong points of a project by drawing a profile line connecting the weights given to the project attributes.

The previous discussion has dealt almost exclusively with project selection. There is a small body of literature dealing with postevaluations, which are conducted after the prime responsibility for a project has moved from the research group to other parts of the organization. Postevaluation attempts to determine how well the research organization is doing in contributing to the company's commercial objectives (Collier and Gee 1973).

According to Porter (1978), Mobil Oil's research division sees five major benefits to postevaluations of R&D: (1) motivating researchers, (2) identifying high risk business objectives, (3) demonstrating research productivity, (4) identifying productive research areas, and (5) increasing confidence in predictive evaluations.

Collier and Gee (1973) endorse postevaluations because they believe that without a valid method for evaluating R&D, it is difficult to know objectively if other procedures for improving the research process are really effective—in their words "It's difficult to determine the effort of the independent variables unless you can measure the dependent variable."

Although relatively little has been written about evaluating the consequences of industrial R&D (Patterson 1983), there are descriptions in the literature of how some companies evaluate research effectiveness. At Mobil, research return ratio (RRR) is used to predict the value of research (Porter 1978). The RRR compares the value of accomplishing a research objective with the cost of doing it. Alcoa has used an indicator called the economic benefit ratio to evaluate R&D on a quarterly basis (Patterson 1983). Laboratory performance is measured by using the ratio of accumulated present values for accomplishments maturing during the quarter to laboratory expenditures for that quarter. Alcoa has identified several benefits from this evaluation effort:

1. It helps to legitimize R&D in financial rather than technical terms.
2. It provides feedback to decisionmakers.
3. It stimulates researchers to pursue research with financial benefit to the company.
4. It makes researchers more aware of the importance of implementation of results, and gets them more involved in the process.
5. It points out where most of the benefits are coming from, thereby helping management determine where to concentrate attention.
6. It creates a more favorable climate for longer range work and funding by demonstrating a mastery of near-term technology.
7. It improves project selection criteria.

Currently, Alcoa sees three major drawbacks to the effort:

1. Sales projections are difficult to make.
2. The synergistic effect of accomplishments often defies accurate separation of benefits.
3. Capital costs of implementation have been ignored.

Collier (1977) has described Borg-Warner Corporation's first 3 years of experience with a two-step R&D evaluation procedure which seeks to determine how well the research department is creating technologically based business opportunities for the company. Step one evaluates how well research has met previously agreed-upon objectives. Step two evaluates the potential value of completed research projects. The interesting feature of this approach is that it estimates the total financial gain represented by research accomplishments. How much of this gain the firm might realize depends on others in the firm.

Limitations of Industrial Research Evaluation

Regarding evaluation of industrial R&D in theory, Clarke (1974) notes, "Obligingly, the same people who design the models also tell us why they are not used." One comprehensive critique, (Baker 1974) identifies seven limitations to using the project selection techniques discussed above:

1. Inadequate treatment of project and parameter interrelations with respect to both benefit contribution and to resource utilization.
2. Inadequate treatment of uncertainty as it impacts on benefit measurement and parameter estimation.
3. Inadequate treatment of multiple, interrelated decision criteria which have no common, natural underlying measure.
4. Inadequate treatment of the time and variant property of the parameters and criteria and the

associated problem of continuity in the research program and staff.

5. A restricted view of the problem which (a) portrays a once-a-year investment decision rather than an intermittent stream of investment alternatives, (b) does not include such attributes as timing of the decision, generation of additional alternatives, and recycling, (c) does not recognize the diversity of projects along the spectrum from basic research to engineering, and (d) views the problem as a decision event rather than as a hierarchical, diffuse decision process.
6. No explicit recognition of the importance of individual R&D personnel.
7. The inability to establish and maintain balance in the R&D program.

Mansfield (1982) adds that many of the models fail to recognize that R&D is essentially a process of buying information. Even unsuccessful projects can provide valuable information; therefore, the real task is to allow for a series of decisions under uncertainty. He goes on to point out that project selection often rests on overly optimistic, unreliable estimates of benefits and costs that reflect both the uncertainty of the undertaking and the desire to "sell" projects to top management.

Although there are few descriptions in the literature on how firms evaluate their project selection processes, generalizations can be made. Quantitative evaluations are done most frequently at the development stage of R&D, for two primary reasons: First, developmental work accounts for the major share of industrial investment in R&D. Second, because development is closer to the commercialization stage of innovation, the risk and cost attributes are easier to estimate. Reliable estimates of both risk and cost are keys to quantitative evaluation. At the exploratory research stage, evaluation consists of comparing proposal attributes with recognized criteria. Almost all evaluations assess benefits from the firm's innovations rather than R&D per se. For this reason, the market looms large in the method described.

OTHER APPROACHES TO RESEARCH EVALUATION

Robert A. Westgate and David N. Bengston[6]

There are two other approaches to research evaluation that do not fit neatly into our discussions of agricultural or industrial research evaluation, but are relevant to the topic. These are the peer review approach used by the Commission of the European Communities, and technology assessment.

Peer Review—Commission of the European Communities (CEC)

The CEC is involved with a variety of projects dealing with European cooperation. It became seriously interested in formal evaluation of research during the early or mid-1970's. Although CEC research does not deal directly with forestry, it is involved in a number of related fields, including energy, environment, raw materials, and agriculture.

In June of 1978, the CEC organized a seminar on the evaluation of R&D (CEC 1979a, 1979b). Research evaluation approaches used in different sectors and in different countries were reviewed and discussed at that time. Based on discussion at the seminar, the CEC developed an evaluation strategy and approach for its projects. This evaluation system was tested on a number of cases, with the results reviewed and assessed at a second conference (Boggio and Gallimore 1982).

The heart of the CEC approach is the traditional peer review model. Within this approach, the CEC recognizes two types of evaluations: (1) internal evaluations, conducted during research program execution, and (2) external independent evaluations, conducted following program completion.

The CEC evaluations attempt: (1) to assess scientific and technical quality of the research, (2) to evaluate the effectiveness of program management, and (3) to determine the practical contributions of program results. Evaluation teams consist of three to six experts, chosen for their expertise and independence concerning the program being evaluated. Evaluations are divided into four phases: (1) orientation of panel members to the research program being evaluated; (2) reaching agreement on evaluation methods, organization, and criteria; (3) actual evaluation of research quality and impacts; (4) final report and recommendations. During the actual evaluation, panel members review contract proposals, study plans, progress reports, final reports, related publications, meeting minutes, seminar proceedings, statistical data, and other materials supplied by researchers and administrators. Analysis is supplemented by interviews and results of questionnaires sent to contractors and, in some cases, users of results.

In analyzing its process, the CEC found that the peer evaluation approach has been generally well accepted, reconfirming the need for independent, outside evaluation (Contzen *et al*. 1982). The choice of experts is critical, as is timing. In the case of an ongoing research program that involves phases, the evaluation should be done early enough to allow input into extension or revised project decisions. Efforts should be made to strengthen the quantitative aspects of the evaluation process. More effort needs to be devoted to evaluating the socioeconomic impacts of research.

The research evaluation approach of the CEC is still evolving. As stated by the Director General for Science, Research and Development of the CEC: "We are in a continuing learning process" (Fasella 1982). He further states:

> We are convinced, in fact, that "peer review" is extremely valid for establishing the scientific and technical merit of the results, for assessing the efficiency of the management and, of major importance, for comparing the results with the original objectives of

[6]*While working on this study, the authors were graduate research assistants, Department of Agricultural and Applied Economics, University of Minnesota.*

> the programme. However, as we proceed from "review" to "evaluation," i.e., we try to establish the "value," the "usefulness" of our results, the opinion of "peers" is no longer sufficient and must be integrated with what could be called appreciation by "users" (Fasella 1982).

The CEC approach is extremely practical and provides some very useful evaluation information. However, in and of itself it does not provide sufficient information by which to judge the value of research. Some evaluation of impacts based on response of users is needed as well. In the case of market-priced outputs, such response shows up in market prices and sales. In the case of research involving nonmarket goods and services, or intermediate technical processes, some other indication of user valuation is needed. Further discussion of variations on the peer review process can be found in Salasin *et al.* (1980), Kennedy (1977), Cleland *et al.* (1982), and Knoppers (1979).

Technology Assessment (TA)

Technology assessment may be defined as policy analysis designed to systematically explore the impacts on society that may accompany the introduction of new technology. The underlying idea is that technology has social consequences which need to be evaluated, and that public policy decisions are based on many evaluation criteria. For discussions of TA methodology, see Coates (1974), Porter *et al.* (1980), Armstrong and Harman (1980), and Lee and Bereano (1981).

In contrast to most forms of policy analysis, TA has been advanced by policymakers and analysts in Federal government (O'Brien and Marchand 1982). Congressman Emilio Daddario introduced the idea of technology assessment with his proposal in 1966 to create a congressional staff that would monitor technological developments for government policymakers (Daddario 1970). The Office of Technology Assessment (OTA) was established by Congress in 1972 and remains the major producer of TA's today. Technology assessment in the private sector has been quite limited (Coates and O'Brien 1982).

Several problems often limit the effectiveness of TA. The first relates to the timeliness of information; because decisionmakers often require information quickly, and because TA is a time-consuming process, decisionmakers' need for information often exceeds analysts' ability to provide it (O'Brien and Marchand 1982). Another limitation is the inherent tradeoff between the broad scope of a TA and the depth to which the technology can be analyzed (Sundquist *et al.* 1982a, 1982b). A broad assessment may produce a great deal of information about potential impacts of an emerging technology, but may not be sufficiently detailed about key decision criteria to be useful to policymakers. The danger is that technology assessments without carefully delineated objectives and boundaries can end up being a mile wide and an inch deep.

Finally, the political environment in which TA takes place has the potential for limiting its effectiveness in decisionmaking. The control of technology involves sensitive issues that touch many interest groups. Some have asked whether TA's do indeed contribute to consensus building or whether they merely fuel political conflicts. O'Brien and Marchand (1982) have commented:

> Assessment of technologies thus is actually extremely fragmented, inexorably incremental, largely uncoordinated, and contingent on the dynamic political pressures of multiple institutions and organizations in the public and private sectors.

Yet, technology assessment, with its flexible methodology, has the potential to provide research policymakers with the types of information they require. In designing studies, care should be taken to avoid the pitfalls discussed by Martino and Lenz (1977) and Berg *et al.* (1978).

Technology assessments have the greatest potential impact on research decisions made at a fairly aggregate level. Individual research projects or small programs are probably inappropriate for this type of analysis, because they typically have more narrow objectives than those addressed by TA. In addition, the resources needed to carry out a TA are likely to be prohibitive at this level.

The use of TA in setting research priorities has received some attention in the literature—e.g., evaluating research results and improving allocation of research funds (O'Brien and Marchand 1982, Coates 1982)—and its application to research management has been discussed (Koppel 1978, 1979). The application of TA to research decisionmaking, however, has been limited, making it an important area for further research.

FORESTRY RESEARCH EVALUATIONS

Hans Gregersen and Christopher D. Risbrudt[7]

In arguing for an annual allocation of $40,000 for testing the physical characteristics of various species of timber in 1893, Bernard Fernow remarked:

> The economy secured to the country at large by this work may best be comprehended from the statement that by the simple demonstration of the value of "bled" timber for building purposes, an increase in the price of the product of nearly 1,000,000 acres in the Southern States has been secured, involving in the assumed appreciation of at least 2,000,000,000 feet, B.M., of lumber, which, if appreciated by only $1 per 1,000 feet, represents a savings of $2,000,000 in value (USDA 1893).

Thus reads a report on one of the earliest forestry research evaluations. Through the years, similar statements regarding the value of forestry research have been made. Although many have not been thought of as "research evaluations," they fit the term in all respects.

For this study we reviewed some 60 forestry "research evaluation" documents, choosing examples to illustrate the current state of the art. Let's begin by looking at some examples of forestry program evaluation. Program evaluation is closely related to research evaluation, and methodologies often overlap. Although the field of forestry research evaluation is relatively young, there is a tradition in forestry of program evaluation. One of the first examples of the latter was Lundgren and King's (1966) evaluation of financial returns from forestry tree improvement programs. In this evaluation, Lundgren and King calculated internal rates of return for long-term and short-term tree improvement programs for red pine and jack pine. They were interested in answering these questions: How much genetic improvement is needed to justify the program test approach? How does one determine which of the species could be improved at the greatest profit? How much return can be expected in tree improvement programs?

In another program evaluation, Risbrudt and Kaiser (1981) evaluated the U.S. Department of Agriculture, Forest Service sawmill improvement program using a cost-benefit approach to determine the relationship between the cost of the program and the benefits resulting from higher yields or improved efficiency in sawmills.

Evaluations of the USDA Combined Forest Pest Research and Development Programs bridge the gap between program evaluation and research evaluation (Cleland *et al.* 1979, Cleland *et al.* 1982, Rose 1983). In the primary evaluation (Cleland *et al.* 1979), three separate approaches were used and then combined in an overall evaluation. The first approach was a benefit-cost evaluation, which provided the evaluators with a basic measure of economic efficiency. The second was a clientele assessment survey, which queried knowledgeable individuals on the effectiveness of the Combined Forest Pest Research and Development Program. The third was an "acceleration evaluation," in which an expert panel compared the expected accomplishments under accelerated effort with those under normal or base-level funding. The third approach is a traditional "with and without," or incremental, evaluation.

An evaluation conducted by the General Accounting Office (1972) was one of the first initiated outside the forestry community to focus specifically on the impacts of forestry research. Evaluators interviewed national forest managers to determine the extent to which they applied 10 innovations resulting from Forest Service research. The evaluators found very little use of the innovations in the field.

In a second study of forestry research initiated outside the forestry community, the U.S. Department of Agriculture, in cooperation with the Office of Management and Budget, interviewed the users and beneficiaries of 15 Forest Service research projects to ascertain whether the research being undertaken was appropriate for the Federal govern-

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[7]*At the time this chapter was being prepared, the author was a project leader, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.*

ment (USDA 1982). The strongly stated conclusion was that the Forest Service research was appropriate.

Early research evaluations initiated within the forestry community were used primarily for long-range planning and policymaking. Methods ranged from quantitative models providing information for resource allocation decisions (Bethune and Hargreaves 1968, Bethune and Clutter 1969) to survey assessments (Fedkiw 1981, Callaham 1981) and descriptions of how a process works (Kennedy 1977, Moeller and Shafer 1981).

In the early 1980's, political and economic changes helped generate increased interest in forestry research evaluation in the U.S. Department of Agriculture and at universities across the Nation. This resulted in a series of studies aimed at developing quantitative methods to evaluate forestry research. Although many of these studies have focused on research methodology, they have also been used in resource allocation or policymaking.

Gregersen *et al.* (1983b) analyzed the impacts of seven major innovations in forest products utilization research. For this study, the evaluators used an *ex ante* benefit-cost approach. The study methods are outlined in figure 5. Even with a very conservative assessment of benefits and an extremely liberal estimate of costs, the calculated rate of return on the investment in forest products utilization research was on the order of 20 percent.

Using an economic surplus approach, Bengston (1984) evaluated returns to structural particleboard research. Benefits were measured only in terms of savings to consumers, ensuring a conservative estimate. Public and private research costs were estimated using industry information, publication counts, publications per scientist, and estimates of costs per scientist. Average internal rates of return ranged from 19 to 22 percent. A sensitivity analysis indicated the results were insensitive to estimates of research costs. Marginal rates of return were from 27 to 35 percent, suggesting that further investment in this type of research would produce attractive rates of return.

Using an approach similar to Bengston's, Westgate (1985) evaluated the impacts of containerized forest tree seedling research. He calculated internal rates of return ranging from 37 to 111 percent, depending on (1) the quantity of containerized seedlings produced in the future, (2) estimates of research costs, and (3) the price discount of containerized seedlings. The internal rate of return was very sensitive to assumptions made for the latter two factors.

Seldon (1985) developed a nonresidual supply function approach to estimate returns to southern

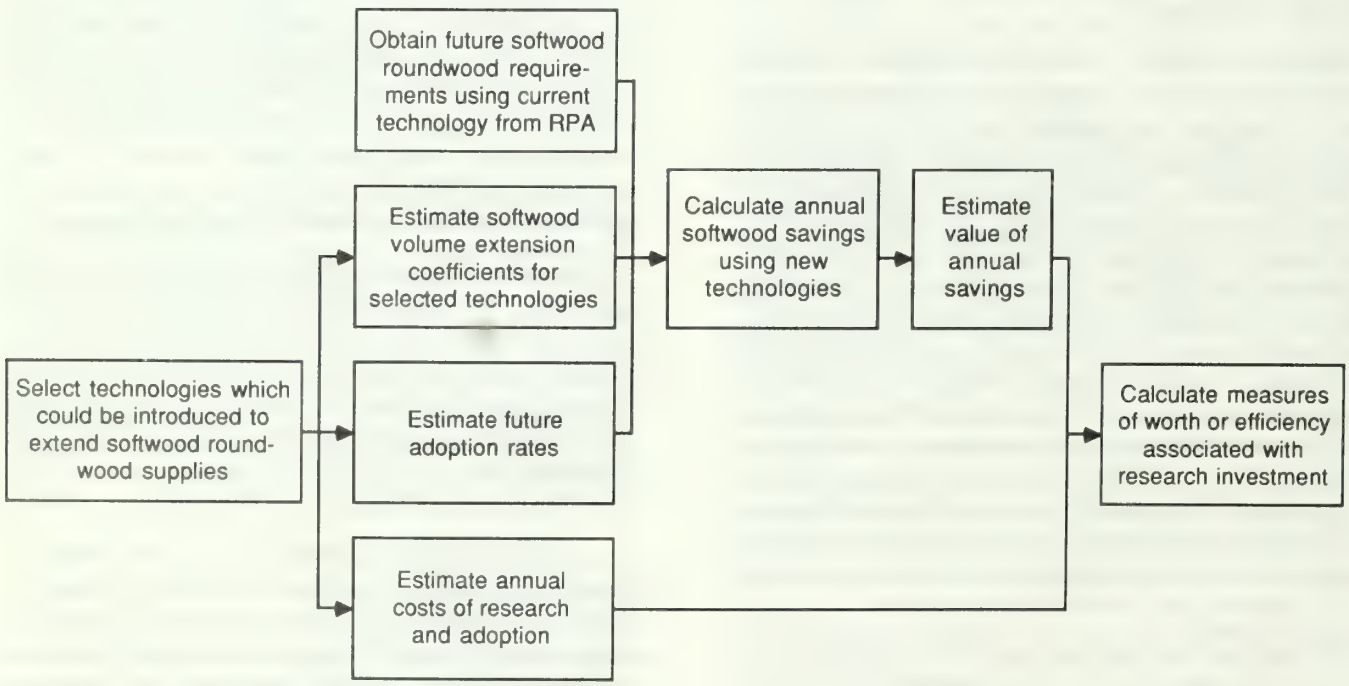


Figure 5.—*Evaluation of utilization research.*

softwood plywood research. He explained the high internal rate of return—422 percent—by the fact that public softwood research was applied research quickly adopted by softwood plywood producers.

In a second evaluation by Bengston (1985a), the rate of return to U.S. lumber and wood products research from 1942 to 1973 was estimated to be 40 percent. After adjusting for interindustry technology flows (allowing for innovations developed in other industries but used to increase productivity in the lumber and wood products industries), the rate of return was calculated at 34 percent. Bengston also adjusted for changes (such as quality) in intermediate inputs, a factor previously ignored.

Bare (1985) evaluated the Regional Forest Nutrition Research Project administered by the University of Washington's College of Forest Resources, and found real after-tax return rates of 9.3 to 12.1 percent. The range in values was caused by differing assumptions concerning the percentage of acreage fertilized annually that can be attributed to the research cooperative.

While the value of new information has received attention in agricultural research evaluation (Hayami and Peterson 1972, Huffman 1978), it has only recently been investigated in forestry. Chang (1985) found that use of a growth and yield model developed for upland oak in New England rather than the Midwestern model used previously resulted in an increase in land expectation value of nearly $50 per acre. By estimating the extent of application of the new model and the costs of research, Chang calculated a benefit-cost ratio in excess of 16:1. Where new information does not lead to significant changes in management practices, the returns would probably not be as large.

The Canadians are also active in research evaluation. Babcock (1973) provides the following observation:

> In a nutshell, all the methodology does is to permit a systematic quantification of tangible and intangible benefits from Canadian Forest Service research, according to national objectives, and ties the estimated benefit to the cost of doing the work. The results of program evaluation are a *guide* to decisionmaking and not a *decisionmaker*.

Within this framework, Babcock discusses research evaluation criteria, definitional programs and projects, and selection of a panel of experts to develop weightings for criteria and ratings for projects. The panel approach to project selection has also been used by the Western Forest Products Laboratory in British Columbia (Kennedy 1977).

Taylor (1973) tried to develop monetary benefit measures for several Canadian forestry research projects, but succeeded in only one of the cases chosen. He states that serious problems with quantifying research benefits in forestry stem from lack of readily accessible data and long production periods.

A review of forestry research evaluation is found in the proceedings of a workshop held recently in St. Paul, Minnesota (Risbrudt and Jakes 1985). A second proceedings, from a forestry research evaluation conference organized by the International Union of Forestry Research Organizations (IUFRO), is also available (Burns 1986). At a more conceptual level, the collection of papers contained in Hyde (1983) provides an overview of research evaluation thinking in the forestry community.

Many of the most useful research evaluations are those done inhouse, and not meant for public scrutiny. The U.S. Department of Agriculture, Forest Service conducts such formal reviews or evaluations of research projects and programs on a regular basis. These normally consist of field visits by Washington Office staff and other specialists or users. Their purpose is primarily to obtain information for decisionmaking.

Other evaluations of university research programs are carried out by the Cooperative State Research Service (CSRS). These reviews or evaluations consist of formal visits to cooperating universities by a review team appointed by the CSRS. Personal judgment, based on review of records and interviews, is the main approach used.

One Forest Service approach, the design of which has not been published, was used to evaluate costs and benefits associated with 1985 RPA research program alternatives (Shafer and Davis 1983). It is a first attempt to evaluate the total Forest Service research effort, and will certainly be subject to major adjustments and refinements. The approach combines use of expert panels with a number of innovative analytical techniques. Although tailormade for the Forest Service, the basic underlying benefit-cost model is the familiar one used in many evaluations. As with so many evaluation or planning exercises, the key challenge is generating or locating acceptable data.

No discussion of research evaluation literature in forestry would be complete without mentioning the seminal papers of Lundgren (1981, 1982, 1983, 1986). He has provided the guidance and insight necessary for expanded efforts to understand and undertake research evaluations in the field of forestry. Although not written to help administrators plan and budget research programs, they do provide useful guidance for setting research evaluation priorities.

Most of the evaluations discussed above have been formal (although not necessarily quantitative) evaluations, undertaken as major assignments. The Forest Service is often called upon to quickly produce research evaluations related to policy issues. For example, several years ago it was asked to identify the extent to which the Federal forestry research effort addressed the concerns and problems of nonindustrial private forest owners. Forest Service staff specialists classified each research project in their respective technical areas into one of six main categories. The results of these classifications were summarized as proportions of line item appropriations for the fiscal year 1983 budget, and then summed to produce a classification profile for the current Forest Service research program. Although lacking in sophistication, this and similar studies have provided practical guidance for administrators charged with making research management decisions.

In summary, most of the quantitative approaches to forestry research evaluation have been variations on the widely used benefit-cost approach (e.g., Gregersen *et al*. 1983a; Rose 1982; Porterfield *et al*. 1975; Taylor 1973; Cleland *et al*. 1979, 1982; Shafer and Davis 1983). But another common approach involves use of opinions or judgments from groups of experts, clientele groups, or other types of panels. This is comparable to the peer group review process found in many other fields. This approach is discussed by, among others, Babcock (1973), Kennedy (1977), Cleland *et al*. (1979, 1982), and Ohman and Skok (1977).

The remaining evaluations either do not fit into neat categories or else fit into the general category of "descriptive" evaluations—i.e., personal judgments, descriptions of the research itself rather than its value, and so forth. A number of rather simple approaches to research evaluation have been used by forestry research administrators and policymakers alike.

Most of the published evaluations have been conducted to provide information for research planning, budgeting, and related activities. Recent studies, although useful in decisionmaking, have been conducted primarily to test research evaluation methodology. Although the field of forestry research evaluation may be characterized as in its infancy, recent work demonstrates that it is moving into a new, more sophisticated phase.

SUMMARY

Pamela J. Jakes

Forestry research evaluation is not significantly different from evaluation of other subjects. Many so-called "research" evaluations, however, are evaluations of social or organizational innovation processes, rather than evaluations of research. The value of research is latent, a value realized through use of its results after they leave the laboratory. Standing alone, research can only be evaluated in terms of norms of the culture which produced it. The factors that cause research to be pulled or pushed out into the world, and the factors that determine its rate of spread and adoption, thus have great bearing on the actual benefits derived.

The distinguishing feature of research as an evaluation subject is the uncertainty of the magnitude of benefits to society resulting from it. This uncertainty increases as one moves from developmental to applied to basic levels of research.

Research evaluation needs in forestry are diverse, due in part to the extremely broad scope of forestry research. Needs vary with discipline (e.g., production vs. social science or trade research), type of research (basic, applied, or developmental), evaluation questions (e.g., resource allocation, justification), and state of research (e.g., preappraisal, monitoring).

While forestry research is broad-based in scope, it is highly concentrated in terms of execution. Roughly two-thirds of U.S. forestry research is done by the U.S. Department of Agriculture, Forest Service and eight private firms. Useful evaluation techniques and the results of evaluations could, therefore, be applicable to a major share of forestry research decisionmakers.

Models or techniques to quantitatively or qualitatively evaluate research have been developed and applied in a great number of disciplines. But few evaluators have attempted to integrate evaluation tools from different disciplines. Little evidence exists of cross-referencing from one area to another, for example, from agricultural economics to evaluation research or to industrial research evaluation. This lack of interaction is certainly partly due to the nature of the U.S. academic reward system, but it may also be partially explained by how evaluators view their efforts: Is it applied social science research or a social service function? This distinction is seen in the evaluation research literature. For the social scientist, disciplinary tenets loom large in the search for valid statements, tenets which are not capable of integration with other disciplinary paradigms.

Thus, one of the main problems with research evaluations is not the availability of models and techniques, but rather the lack of specificity of objectives and purposes, lack of administrative support (or market for research evaluation results), and lack of adequate data. Attention needs to be devoted more to the process of research evaluation—to the ways in which objectives are specified, relevant data are generated, support is obtained, and appropriate models and techniques are chosen to meet real-world constraints.

While all decisionmakers use evaluations, very few use formal, rigorous evaluations. Informal evaluations appear to serve mainly as background information for shaping future program directions. From the industrial and evaluation research literature, we find that decisionmaking processes are often not "evaluation friendly"—that is, they do not lend themselves to the injection of specific information at specific points in time. Clear decisions of the "go/no go" variety are rare; rather, decisions are made incrementally. An evaluation which collapses all aspects of research into a single number is mainly limited to specific uses, such as *ex post* justification. Such evaluations fail to provide useful information on evolving, ongoing programs. To the extent that an evaluation seeks to facilitate an open and knowledgeable decisionmaking process, it needs to be less sectarian and judgmental and more inclusive.

It is evident that credibility is a key factor in determining the ultimate usefulness of a research evaluation. Credibility relates to such factors as who sponsors the evaluation, who carries it out, the clarity of the results, the perceived level of uncertainty surrounding the results, and the agreement of the results with decisionmakers' views and previous information. This does not mean that the only evaluation worth doing is an external evaluation. Internal evaluations can be very beneficial, especially in terms of learning from the evaluation process itself. Also, trust develops through active participation.

What is needed in the way of future research on forestry research evaluation? It is essential that the questions of who makes decisions and what types of decisions are made in the forestry research system be studied in much greater detail. It is only possible to design relevant evaluations when we know how they are used in the decisionmaking process.

Some case studies now exist in forestry to indicate the usefulness of certain research evaluation approaches. However, other alternatives need to be explored. For many types of forestry research evaluation, a broad interdisciplinary approach is needed, and combinations of quantitative and qualitative evaluation tools should be tried. Impacts from the transfer of research results across national boundaries should be assessed.

Some specific topics for future research on research should include:

- The link between research planning and evaluation and technological forecasting.
- Technology assessment and research planning.
- Evaluation measures other than economic efficiency.
- The link between international technology transfer and research progress in the United States.
- What we can learn from research failures, or research that does not accomplish its intended task.
- How research directions change over time in relation to budgets and the general economy.
- Marketing approaches to research evaluation.
- How the potential size of user populations for given research outcomes could provide useful information for research decisions.
- New ways to identify promising areas for future forestry research.

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Reviews research evaluation techniques in a variety of fields and assesses the usefulness of various approaches or combinations of approaches for forestry research evaluation. Presents an evaluation framework that will help users develop an approach suitable for their specific problem.

KEY WORDS: Evaluation research, research impacts, research benefits.

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NORTH CENTRAL

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General Technical Report **NC-111**

Manager's Handbook for Balsam Fir in the North Central States

William F. Johnston



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Northern hardwoods—GTR-NC-39
Elm-ash-cottonwood—GTR-NC-98

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FOREWORD

This is one of a series of manager's handbooks for important forest types in the North Central States. The purpose of this series is to present the resource manager with the latest and best information available on managing these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. Ways to modify management practices to maintain or enhance other values are included where sound information is available.

The handbooks have a similar format, highlighted by a "Key to Recommendations." Here the manager can find, in logical sequence, the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbooks. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important types can be continually improved.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to several resource managers who shared their knowledge about the balsam fir type during field trips and to several technical reviewers who made many helpful comments. In particular, Thomas R. Biebighauser of the Superior National Forest provided information on managing the type for wildlife.

CONTENTS

	Page
DEFINITION OF TYPE	1
SILVICAL HIGHLIGHTS	1
MANAGEMENT OBJECTIVES AND NEEDS	1
KEY TO RECOMMENDATIONS	3
TIMBER MANAGEMENT CONSIDERATIONS	4
Controlling Growth	4
Site Productivity	4
Rotation	5
Intermediate Treatments	6
Controlling Establishment and Composition	8
Reproduction Requirements	8
Silvicultural Systems	9
Conversion and Alternating Crops	11
Controlling Damaging Agents	14
Spruce Budworm	14
Rot and Wind	16
Other Agents	17
OTHER RESOURCE CONSIDERATIONS	18
Boughs and Christmas Trees	18
Wildlife Habitat	18
Esthetics	20
Water	20
APPENDIX	21
Yield and Growth	21
Site Index	22
TWIGS	23
Metric Conversion Factors	24
Common and Scientific Names of Plants and Animals	25
REFERENCES	25
PESTICIDE PRECAUTIONARY STATEMENT	27

MANAGER'S HANDBOOK FOR BALSAM FIR IN THE NORTH CENTRAL STATES

William F. Johnston,[1] *Principal Silviculturist, Grand Rapids, Minnesota*

DEFINITION OF TYPE

Balsam fir[2] is pure or comprises a majority of the stocking in the balsam fir type. The type is No. 5 of the Society of American Foresters forest cover types and one of six Lake States types that is combined into the spruce-fir type group by the USDA Forest Service. The balsam fir type occupies 1.9 million acres of commercial forest land in the northern Lake States; 45 percent of this total occurs in Minnesota, 33 percent in Michigan, and 22 percent in Wisconsin.

The balsam fir type often grades into one of the other forest types included in the spruce-fir type group. Also, balsam fir is an important component in a number of other types such as black spruce, aspen, and paper birch.

SILVICAL HIGHLIGHTS

The balsam fir type grows under a wide range of soil and other site conditions, but it is most common on cool, wet-mesic sites where strongly to moderately acid (pH 5.1 to 6.0) Spodosols and Inceptisols are characteristic soils. Although balsam fir grows in pure stands, the balsam fir type more often occurs as mixed stands. On dry-mesic to mesic uplands, balsam fir is commonly mixed with such trees as white spruce, paper birch, and quaking aspen; on wet-mesic to wet lowlands, it is commonly mixed with black spruce, northern white-cedar, and black ash.

Balsam fir seeds prolifically and is able to become established in dense shade. It can survive many years of suppression and still respond to release, but best growth is in about 50 percent or more of full sunlight. An understory of balsam fir seedlings is almost ubiquitous in several upland and lowland forest types. Balsam fir understory trees often succeed overmature stands of quaking aspen and paper birch, and they commonly replace northern white-cedar on cutover swamps. Balsam fir may be a climax type on poorly drained clay soils, but on mesic sites it is gradually replaced by shade-tolerant northern hardwoods such as sugar maple.

The main damaging agents of balsam fir are the spruce budworm, trunk and root rots, and wind. The spruce budworm causes the most damage in overmature stands or dense stands that are pure or have a high proportion of fir. The principal trunk-rot fungus, red heart rot, causes two or three times more cull than root (or butt) rots in balsam fir. Root rots, however, make the tree susceptible to wind damage; on uplands they limit the pathological rotation to about 70 years. Because of rot and shallow rooting, balsam fir is especially vulnerable to wind damage in old, unmanaged stands on wet, shallow soils.

MANAGEMENT OBJECTIVES AND NEEDS

Specific objectives in managing the balsam fir type may differ greatly depending on the forest owner's overall objective and on present or expected stand conditions. Balsam fir has usually had low timber value, and periodically it has been severely damaged by the spruce budworm. A common objective is to convert to another forest type. Conversion alternatives will be discussed later in relation to such factors as site productivity, stand composition, and the spruce budworm.

The timber value of balsam fir could increase substantially in the future because the Lake States has the potential to use much more fir for pulpwood, reconstituted wood panels (such as waferboard), and structural lumber (mainly studs). However, greater utilization of fir is hindered by several factors, including high harvesting costs. Thus, an important

[1] *Present location: Columbia, Missouri.*

[2] *For scientific names of plants and animals, see Appendix, p. 25.*

timber management objective is to grow stands of even-aged balsam fir that are large enough to be harvested efficiently with mechanized equipment but small enough not to be conducive to spruce budworm attack. Medium-sized stands of about 40 acres usually are recommended. To further reduce costs and increase utilization, these stands need to produce at least moderate volumes of fir that are harvested before fungi appreciably decay or stain the wood.

In many parts of the northern Lake States the balsam fir type is important for wildlife habitat, especially for winter cover. Thus, another common objective is to maintain or improve the type for wildlife while still producing a moderate, sustained yield of merchantable timber. Unless special funds are available, habitat management will have to be done through timber management. This will require careful long-range planning and coordinated action by timber *and* wildlife managers.

The balsam fir type is significantly affected by the spruce budworm, rots, and wind. These damaging agents cause substantial timber losses and, through tree mortality, can seriously reduce winter cover or esthetic values. So, whether the primary objective in managing balsam fir is timber production, wildlife habitat, or esthetics, we need to be able to control these agents in present and future stands.

The best way to manage balsam fir stands in terms of age structure and intensity depends on the owner's objective. Even-aged stands are preferred for timber and wildlife management; uneven-aged stands tend to be better where esthetic values are paramount. Because the timber value of balsam fir is usually low, most stands will have to be managed extensively. However, moderately intensive management to shorten pulpwood rotations or to produce small saw logs, for example, may be possible where economic conditions are particularly favorable.

The practices recommended here should lead to improved management of the balsam fir type. Unfortunately, little information exists on the costs and returns of using these practices. General comments about costs are made in several instances, but most economic decisions will have to be based on the particular situation and on the manager's experience and judgment.

KEY TO RECOMMENDATIONS

Recommendations for managing balsam fir stands are given in the following key, which contains a series of alternative statements about various stand conditions or management objectives. The statements include references to the text where these conditions and objectives are discussed. With accurate knowledge of a stand and the owner's overall objective, the resource manager can find the recommended practices.

To use the key, begin with the first pair of like-numbered statements. Select the one statement that better describes the stand in question or owner's objective and obtain a final recommendation, a partial recommendation plus a number, or a number alone. If a number is given, repeat the selection process until a final recommendation is reached. The overall recommendation is the sum of the partial recommendations arrived at while going through the key.

During a spruce budworm outbreak, also consult the key by Flexner *et al*. (1983). Their key illustrates a variety of options available for dealing with vulnerable spruce-fir stands. It stresses minimizing current timber losses and is general enough to be useful throughout the Lake States.

1. **Balsam fir acceptable type** *and* **site suitable** ..... MAINTAIN OR ALTERNATE FIR 2
   See "Management Objectives and Needs," p. 1; "Site Productivity," p. 4; and "Conversion and Alternating Crops," p. 11
1. **Balsam fir unacceptable type**; *or* **fir acceptable but site unsuitable** 13

   2. **Spruce budworm a minor problem** 3
      See "Spruce Budworm," p. 14
   2. **Spruce budworm a major problem** 10

3. **Stand immature** 4
   See "Rotation," p. 5
3. **Stand mature or uneven-aged** 7

   4. **Balsam fir vigorous, even if suppressed** 5
      See "Intermediate Treatments," p. 6
   4. **Balsam fir weakened by suppression** ..... CLEARCUT WHEN OVERSTORY MATURE .. 12

5. **Stand suitable for intensive management** 6
   See "Rotation," p. 5; "Intermediate Treatments," p. 6; and "Rot and Wind," p. 16
5. **Stand suitable only for extensive management** ..... REPRODUCE FIR WHEN MATURE

   6. **Balsam fir suppressed** ..... RELEASE
      See "Intermediate Treatments," p. 6
   6. **Balsam fir free to grow** ..... THIN WHEN FEASIBLE

7. **Rot and wind a minor problem** 8
   See "Rot and Wind," p. 16
7. **Rot and/or wind a major problem** ..... CLEARCUT ... 12
   See "Silvicultural Systems," p. 9

   8. **Even-aged management preferred** 9
      See "Management Objectives and Needs," p. 1
   8. **Uneven-aged management preferred** ..... USE SELECTION
      See "Silvicultural Systems," p. 9

9. **Balsam fir advance growth adequate** ..... CLEARCUT ... 12
   See "Reproduction Requirements," p. 8; and "Silvicultural Systems," p. 9
9. **Balsam fir advance growth inadequate** ..... USE SHELTERWOOD ... 12

(Key continued on next page)

(Key continued)

10. Stand merchantable 11
See "Rotation," p. 5

10. Stand unmerchantable ..... RELY ON NATURAL REPRODUCTION

11. Balsam fir advance growth adequate; *or* **top-kill and/or mortality present**; *or* **rot and/or wind a major problem** ..... CLEARCUT 12
See "Reproduction Requirements," p. 8; "Silvicultural Systems," p. 9; "Spruce Budworm," p. 14; and "Rot and Wind," p. 16

11. Balsam fir advance growth inadequate; *and* **top-kill and mortality absent**; *and* **rot and wind a minor problem** ..... PRESALVAGE 12

12. Slash cover likely to favor fir reproduction ..... SPREAD SLASH EVENLY
See "Reproduction Requirements," p. 8; and "Silvicultural Systems," p. 9

12. Slash cover likely to hinder fir reproduction ..... SKID FULL TREES

13. Stand merchantable ..... HARVEST AND CONVERT
See "Rotation," p. 5; and "Conversion and Alternating Crops," p. 11

13. Stand unmerchantable 14

14. Spruce budworm a minor problem 15
See "Spruce Budworm," p. 14

14. Spruce budworm a major problem ..... CONVERT
See "Conversion and Alternating Crops," p. 11

15. Stand likely to be merchantable in 20 years or less ..... HARVEST WHEN MERCHANTABLE AND CONVERT
See "Rotation," p. 5; and "Conversion and Alternating Crops," p. 11

15. Stand likely to still be unmerchantable in 20 years ..... CONVERT

TIMBER MANAGEMENT CONSIDERATIONS

Controlling Growth

Site Productivity

The balsam fir type grows under a wide range of site conditions in the Lake States; thus, growth rate differs greatly. Site index, or the height of dominant and codominant trees at age 50, ranges from more than 70 feet on the best sites to less than 20 feet on the poorest (see Appendix, fig. 7, for site index curves). A site index of 25 feet is about the minimum for commercial forest land.

Yield tables that use site index are available for spruce-balsam fir stands but not for pure fir stands. The yield per acre of fully stocked, even-aged spruce-fir stands at age 60—the approximate financial rotation for balsam fir—ranges from 2,600 cubic feet of merchantable wood on good sites to 1,300 cubic feet on poor sites. (See Appendix, page 21, on how to estimate the yield and growth of balsam fir stands.)

Balsam fir is found over most of the gradient from wet to dry sites. However, it is most common on wet-mesic sites where adequate soil moisture is available throughout the growing season and standing water may be present during part of the season. Wet-mesic sites often occur along swamp borders or on poorly drained uplands, particularly those with clay soils. Northern white-cedar and black ash are characteristic associates on these sites, whereas white spruce is a characteristic associate on somewhat drier sites.

Balsam fir also commonly grows on mesic sites where adequate soil moisture is available throughout the growing season. Fir may even be the dominant type on these sites after disturbance. The trend on mesic sites, however, is for fir to be gradually replaced by shade-tolerant northern hardwoods such as sugar maple. Balsam fir is sometimes an important associate on wet sites where standing water is present throughout the growing season. But these sites are usually dominated by black spruce and tamarack. To produce timber efficiently, the balsam fir type should be managed mainly on wet-mesic sites where it is well adapted and easy to maintain.

The balsam fir type grows on a wide range of mineral and organic soils that generally fall within the following soil orders: Spodosols, Inceptisols, and Histosols. Formerly called podzols, Spodosols character-

stically have a thick layer of raw humus and a well-defined E (formerly A_2) horizon, which is usually gray from leaching. Inceptisols include poorly developed soils such as those formerly called humic gleys. The latter are generally mottled and are periodically waterlogged. Histosols are organic soils (peats) that originate under water-saturated conditions.

Site productivity for balsam fir is usually expressed in terms of site index, which (along with age) is needed to determine yield and growth. Balsam fir site index is most reliable when estimated from a site index equation or from curves based on the total height and total age of dominant and codominant firs growing in even-aged stands (see Appendix, p. 22 and fig. 7). To use the equation or curves properly, trees measured for site index (site trees) should be uninjured dominant and codominant firs that are at least 20 years old and have never been suppressed.

Unfortunately, many even-aged stands do not have suitable site trees for balsam fir. The existing firs often are not free of suppression because they are either overtopped or have developed from the understory. Also, some trees may have been injured in the past; for example, they may have a broken top or be deformed from spruce budworm attack. In these cases the site index of balsam fir can be estimated from the site index of certain associated species, provided that at least one has suitable site trees. Comparative site indexes for balsam fir and some common associates are given in the following generalized tablulation:[3]

Balsam fir	Quaking aspen	Paper birch	Black spruce	Northern white-cedar
(Site index, feet)				
60	70	70	60	40
50	60	55	50	35
40	50	40	40	30
30	35	25	30	25

Site index measurements are unreliable in uneven-aged stands because most trees that appear suitable probably have been suppressed earlier. Measurements are also unreliable in stands less than 20 years old (unless quaking aspen or paper birch is present[4]) and in stands severely disturbed by harvesting or damaging agents. Under these conditions, estimate site index without using site trees.

[3]*Based on equations from Carmean (1982); see Appendix, p. 23.*

[4]*Site index curves beginning at 10 years of age are available for quaking aspen (Perala 1977) and paper birch (Tubbs 1977).*

Soil moisture availability and stand composition indicate general site classes. For example, mesic sites with a northern hardwood component usually have a balsam fir site index from 50 to 60, whereas wet (swamp) sites with a black spruce or northern white-cedar component have a site index of about 35. In addition, general site classes for balsam fir can be determined from soil characteristics as shown in the following tabulation:[5]

Site index	Drainage and textural class
60	Well-drained loams
50	Moderately well-drained silt loams, clay loams, and clays
40	Well- to poorly drained sandy loams and sands; well-decomposed peats (mucks)
30	Excessively drained sands; moderately decomposed peats

Fertilizing probably would increase balsam fir's growth rate on some sites in the Lake States, but no specific guidelines are available. Gross periodic growth increased moderately in dense, unmanaged, 45- to 60-year-old balsam fir stands in eastern Canada after applying 150 to 200 pounds per acre of nitrogen (as urea). Unfortunately, tree mortality was high in these stands, so volume losses often exceeded fertilization gains. Thus, fertilizing of balsam fir is not recommended in dense, unmanaged, 45-year-old or older stands. However, some evidence indicates that nitrogen fertilizer (especially ammonium nitrate) may be beneficial when applied to younger stands where stocking has been reduced by spacing or thinning.

Rotation

Balsam fir stands break up at fairly young ages even though individual trees may live for 200 years. This is because root (or butt) rots begin entering balsam fir at about 25 to 30 years; eventually the trees are weakened, which leads to severe windthrow and windbreakage.

Root rot begins sooner on uplands than in swamps. Balsam fir stands in Michigan's Upper Peninsula break up at about 70 years on uplands, 80 years on transition sites, and 90 years in swamps. These pathological rotations are too long, however, for timber management because wind damage and cull are already substantial by these ages.

For maximum yield and utilization of balsam fir pulpwood, rotations should be shortened enough to

[5]*Adapted from Bowman (1944).*

minimize wind damage and to eliminate decayed or stained wood caused by rot fungi. Shortening rotations also may help reduce spruce budworm losses. Based on Michigan findings (Prielipp 1957), these shorter "quality" or financial rotations are as follows:

Type of site	Rotation
	(Years)
Upland (dry to mesic)	45 to 50
Transition (wet-mesic)	55 to 60
Swamp (wet)	65 to 70

These rotations are for total age. However, balsam fir often has butt rot or has originated from old advance growth, thus making it difficult to determine age. To obtain consistent total ages, see Appendix, page 22.

Mean annual growth of even-aged spruce-balsam fir stands peaks at about 60 years in northern Michigan and northeastern Minnesota. This means the foregoing "quality" rotations, which center around 60 years, should provide maximum or near-maximum yields. However, it is important to recognize the risk of spruce budworm losses when growing balsam fir beyond age 45 (see p. 14).

In Michigan's Upper Peninsula the incidence of root (or butt) rot on uplands increases with the presence of fragipans and with the proportion of northern hardwoods. Thus, the rotations recommended for upland sites (45 to 50 years) probably should be a little shorter where fragipans are present or the proportion of northern hardwoods is high.

If the objective is to produce small saw logs, rotations will probably have to be longer than those recommended for pulpwood. However, by using intermediate treatments such as release and thinning (see next section), it should be possible to grow sawtimber trees on rotations only a little longer than those for pulpwood. Substantially longer rotations should be avoided because they greatly increase the risk of losses from wind, rot, and spruce budworm.

Uneven-aged stands have trees of various ages (or sizes), so the whole stand is not harvested at one time as are even-aged stands. Instead, the older or larger trees are harvested periodically in uneven-aged stands. To minimize wind damage and cull, balsam fir trees should be cut by the time they reach the "quality" rotation and certainly before they exceed the pathological rotation. To make uneven-aged stands less vulnerable to spruce budworm damage, periodically harvest large firs because budworms that spin down from them kill most shorter firs during an outbreak.

Intermediate Treatments

Research and experience are limited on how to manage immature stands of balsam fir. Because it is very shade tolerant, balsam fir is commonly an understory species or forms dense thickets. However, intermediate treatments offer an excellent opportunity to control species composition and speed up development of dense fir stands. Unfortunately, they often produce little or no immediate return and can be justified only on areas suitable for intensive timber management (fig. 1).

Despite its shade tolerance, balsam fir grows best in about 50 percent or more of full sunlight. This means release from overtopping shrubs or hardwoods is needed to obtain the tree's full growth potential. The degree to which competing vegetation should be controlled, however, depends on the management objective and type of site. Unless balsam fir timber is the only objective, mixed stands—with fir comprising from 50 to 80 percent of the basal area—are probably best for enhancing wildlife habitat and esthetics (see p. 18 and 20). Also, mixed stands will reduce the potential for spruce budworm damage



Figure 1.—*These sawtimber-sized balsam firs developed following release of vigorous understory trees more than 20 years ago. Overtopping hardwoods (mainly black ash) were removed carefully in winter.*

(see p. 14). On wet and wet-mesic sites, balsam fir will eventually grow above associated hardwoods; but on mesic sites it may become severely suppressed, especially by northern hardwoods.

Balsam fir generally responds well to release; diameter growth rate at least doubles within a few years after release. For best results the trees should be released while they are still young and vigorous. Indicators of such trees are a current annual height growth of 6 inches or more, a fairly pointed crown, and smooth bark with raised resin blisters. Older, severely suppressed trees—current annual height growth of 1 or 2 inches, flat-topped crowns, and rough bark—should not be released regardless of their size. Even small trees often are old and so respond poorly to release and have a high incidence of rot.

Information from the Northeastern States indicates that a single release or cleaning about 8 years after final harvest or when stand height averages from 6 to 10 feet is usually enough to ensure balsam fir dominance. Aerial herbicide spraying is the most practical way to kill back overtopping shrubs or hardwoods. Selective herbicides for releasing balsam fir include 2,4-D, glyphosate (Roundup[6]), and triclopyr (Garlon); hexazinone (Velpar) also shows promise. The most economical herbicide is 2,4-D, which is effective on quaking aspen, paper birch, black ash, beaked hazel, speckled alder, and willow. Glyphosate is effective on a broad spectrum of woody and herbaceous vegetation (including grasses, some sedges, and bracken fern), whereas triclopyr is effective only on broadleaved species. Glyphosate is especially useful for controlling red raspberry and American beech; triclopyr is better for maples.

At present the two most important herbicides for releasing balsam fir are 2,4-D and glyphosate. A low volatile ester of 2,4-D is generally effective when applied at a total rate of 3 pounds acid equivalent in at least 4 gallons of water per acre. Spray when the new growth of balsam fir has hardened off but shrubs and hardwoods are still susceptible—from late July to early August. Glyphosate is effective when applied at a rate of 1 1/2 pounds active ingredient in at least 5 gallons of water per acre. Spray before foliage turns color or frost occurs—late summer or early fall.

Other herbicides may become available and herbicide labels are constantly revised. Thus, the manager should be alert to more effective or economical herbicides and should always follow specific label instructions. Herbicide spraying should be done carefully, following all pertinent precautions and regulations (see Pesticide Precautionary Statement, p. 27). It is particularly important not to contaminate open water.

Aerial herbicide spraying cannot be used if a mixed stand with some hardwoods is desired. Instead, crop trees needing release are selected and then individual trees within about 3 feet of them are either treated with herbicide or felled. Although it costs more than aerial spraying, injecting herbicide into the stem with a tree injector is more efficient than felling with a power brush saw. Herbicide injection can also be used to kill large, unwanted residual trees on harvest areas and it is a promising alternative to aerial spraying for small stands.

The herbicides commonly used for injection are MSMA and Tordon 101 (a combination of picloram and 2,4-D). These herbicides are usually applied undiluted, using 1 or 2 milliliters per injection at about 2-inch intervals around the stem. Another effective herbicide for injection is glyphosate (Roundup); as a 20 percent solution in water, it should be injected at the rate of 2 milliliters per 2 to 3 inches of d.b.h. For safe and efficient use of these herbicides, always follow specific label instructions.

Desirable stand densities are not known for optimum timber growth of balsam fir in the Lake States. Densities that favor fast diameter growth are recommended because they make it possible to grow pulpwood on shorter rotations or to produce saw logs before decay becomes serious. Stocking guides for even-aged spruce-balsam fir stands in the Northeastern States provide estimates of desirable densities. For unmanaged sapling stands, average number and spacing of potential crop trees required to produce at least the recommended minimum stocking of crop trees (curve B in fig. 2) are given in the following tabulation:[7]

Average stand diameter	Potential crop trees	
	Number per acre	Spacing
(Inches)		(Feet)
1	1,650	5 × 5
2	1,350	5 1/2 × 5 1/2
3	1,050	6 1/2 × 6 1/2
4	850	7 × 7

A stocking chart can be used to determine the maximum and minimum stocking levels recom-

[6] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

[7] *Adapted from Frank and Bjorkbom (1973).*

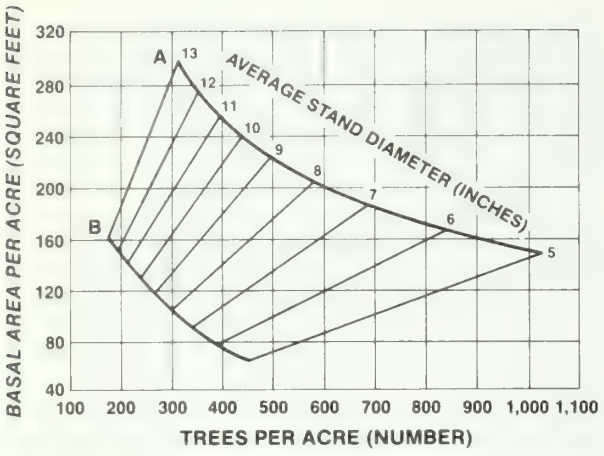


Figure 2.—*Stocking chart for even-aged spruce-balsam fir stands. Adapted from Frank and Bjorkbom (1973) and based on data from the Northeastern States. The maximum and minimum stocking levels recommended for managed stands are represented by curves A and B, respectively.*

mended for managed stands with an average diameter of 5 inches or larger (fig. 2). If the average stand diameter is 6 inches, for example, the maximum stocking is about 830 trees and 170 square feet of basal area per acre; the minimum stocking is about 400 trees and 80 square feet of basal area per acre.

Where intensive management is feasible, spacing or thinning is recommended to reduce stocking in dense balsam fir stands. If done in young stands, these treatments shorten pulpwood rotations to about 45 years, compared to 60 years or more in dense, unmanaged stands. This is because spacing or thinning greatly increases average d.b.h., compared to the small d.b.h.'s in fully stocked (normal) stands (see Appendix, table 1). Shorter rotations should minimize losses to wind, rot, and spruce budworm. Also, by increasing average tree size and making the stand more uniform, spacing or thinning should reduce harvesting costs.

Dense stands between about 10 and 20 years old should have their stocking reduced by spacing or precommercial thinning (see foregoing tabulation). However, neither treatment is needed in young stands that have been hand released or cleaned to favor crop trees. Commercial thinning (at least 5 cords per acre) may be feasible between 25 and 35 years of age (see fig. 2). But heavy thinning must be avoided or substantial wind damage may result. If the average stand diameter is 5 inches or larger, only about one-third of the total basal area should be removed at one time.

A combination of mechanical and manual spacing (or precommercial thinning) probably is the best way to reduce stocking in dense, young stands of balsam fir. Up to half the trees should be eliminated by clearing narrow alternate lanes with mechanized brush cutters or crushers. Then the remaining strips of trees should be thinned by hand. Individual balsam firs can be injected with herbicide or felled as described earlier for hand release.

Unfortunately, little is known about the application or results of the above guidelines to reduce stocking in young fir stands. Effective and economical machines for clearing narrow lanes are not readily available. Care is needed to avoid leaving unwanted trees in exceedingly dense stands. If herbicide injection is used, some nearby crop trees may also be affected because root grafts are common in balsam fir. If trees are felled, no live branches should remain on the stump or they may develop into new trees. Finally, crop trees left exposed after heavy thinning may be damaged by sunscald. Thus, the guidelines in the preceding paragraph should be tested before being used on a large scale.

In commercial thinning well-distributed, high-quality crop trees are left for future growth and less desirable or high risk trees are cut. Harvesting should be done carefully to minimize wounding—and thus subsequent decay—of residual balsam firs (see p. 17).

Controlling Establishment and Composition

Reproduction Requirements

Balsam fir begins to produce seed regularly at about age 30; good seed crops generally occur at 2- to 4-year intervals. In good seed years fir stands yield 5 or more pounds of seed per acre, which is equivalent to 300,000 or more seeds. But cone production may be greatly reduced if the trees have been recently defoliated by the spruce budworm. In some years up to 90 percent of the seed may be destroyed by insects, particularly the balsam fir seed chalcid. Nevertheless, the supply of fir seed is usually ample for natural reproduction.

Balsam fir cones ripen from late August to early September and most of the seed is wind-dispersed in September and October. The effective seeding distance from a mature tree ranges from 80 to 200 feet, depending on such factors as tree height and amount of seed. Many of the seeds, however, stick to the cone scales and fall near the base of the tree.

Most balsam fir seed germinates from late May to early July and practically none remains viable in the forest floor more than 1 year after dispersal. Optimum germination temperatures range from about 64° to 84° F, but temperatures down to at least 54° F are suitable. Within the range of suitable temperatures, moisture is more important than light for germination and initial establishment. If enough moisture is available, seeds will germinate on almost any seedbed and seedlings will survive for the first few years with only 10 percent of full sunlight.

The soil must be disturbed to obtain new balsam fir seedlings promptly after harvesting. The closer seeds lie to mineral soil, the better the initial establishment. Medium-textured mineral soil with some shade is the best seedbed. Unincorporated organic material (duff) with no shade is a poor seedbed, especially if the duff is more than 3 inches thick. Thus, scarification under a shelterwood should produce an excellent seedbed.

Frequent seed crops and balsam fir's ability to become established in dense shade assure a continuous supply of small seedlings in most mature fir stands. But development of this advance growth is determined largely by the amount and character of overhead competition. To obtain the 50 percent or more of full sunlight required for optimum growth of crop trees, openings probably need to be larger than those created by removing individual trees. However, if a stand's basal area is reduced by half or more, competition may become severe from such vegetation as bracken fern, red raspberry, and hardwood sprouts (especially the maples). To develop satisfactorily in heavily cut stands, advance growth should be at least 3 feet tall on sites with average competition and 6 inches tall on sites with little or no competition.

Slash is another factor that can significantly affect balsam fir reproduction. A light slash cover usually favors advance growth survival and new seedling establishment. This is especially true on hot, dry sites where some shade is needed to conserve soil moisture and to moderate surface temperatures. In contrast, a heavy slash cover buries advance growth and creates poor seedbeds; it also hinders scarification and can be a fire hazard. Thus, disposal of some slash should favor fir reproduction in heavily cut stands. Full-tree skidding is recommended to reduce the large amount of slash produced by shelterwood cutting and clearcutting. (See page 18 for control of skidding damage.)

Artificial reproduction of balsam fir is seldom considered because advance growth is almost ubiquitous in many forest types. This no doubt explains why little is known about the requirements for planting or direct seeding balsam fir after harvesting. However, some Christmas tree growers plant balsam fir and so can advise forest owners on planting practices. Recent nursery experience indicates that high-quality fir seedlings can be grown easier in containers than as bare-root stock. Nevertheless, if planting is desired, white spruce is recommended because it has important advantages over balsam fir (see p. 13), including a higher survival rate and little browsing damage by white-tailed deer.

Although practically no balsam fir has been planted for timber management, planting offers better prospects for success than direct seeding. Before direct seeding can be recommended, ways to prepare seedbeds and to protect seeds from seed-eating animals must be developed.

Silvicultural Systems

Balsam fir can be managed in both even- and uneven-aged stands. This is possible because fir reproduction grows best in about 50 percent or more of full sunlight, and yet it commonly becomes established in the understory and is very shade tolerant. Even-aged stands—which include those that originate under aspen or paper birch (see p. 12)—are generally preferred. They are simpler to manage than uneven-aged stands and cost less to harvest. Uneven-aged stands are mainly preferred for special esthetic, wildlife, or other values and will usually make up only a small proportion of managed fir forests. Also, uneven-aged stands should be limited to wet-mesic or similar sites where balsam fir can be maintained with little cultural work and without serious losses from rot or wind.

Depending on stand conditions, either clearcutting or shelterwood cutting is recommended for reproducing balsam fir in even-aged stands. The seed-tree system is not suitable because the residual (seed) trees are too vulnerable to wind damage to be a reliable seed source. The clearcutting and shelterwood systems are usually used in mature, even-aged balsam fir stands. Both systems are also suitable for converting merchantable, uneven-aged fir stands to new, even-aged stands. Clearcutting is necessary, of course, where mortality of overstory firs—mainly from rot, wind, and/or spruce budworm—is expected to be too high to maintain a shelterwood.

Clearcutting is most appropriate for balsam fir stands in which fir advance growth is not only well developed but also well stocked. A milacre[8] stocking

[8] *A milacre is 1/1,000 acre and usually square (6.6 feet on a side).*

from 50 to 60 percent *after* harvesting is considered adequate for seedling-sized firs. Sapling-sized firs should be adequately stocked if the number or spacing of potential crop trees after harvesting approximates the values given in the tabulation on page 7. To achieve adequate stocking after clearcutting, it is usually necessary to harvest the stand carefully; it also may be beneficial to remove some slash (see p. 9 and 18).

The best size, shape, and arrangement for clearcut areas depend on stand conditions and the owner's objective. If well stocked with established fir reproduction, entire stands or large patches (10 acres or more) can be reliably reproduced by a single cutting. Because these areas are large, harvesting and future treatments such as thinning can be mechanized to reduce costs. However, large-scale clearcutting usually has a negative effect on wildlife habitat and esthetic values (see p. 18 and 20). Clearcutting in strips or small patches (from 1 to 5 acres) is recommended where multiple-use management is important. Clearcut strips or small patches are also recommended where fir advance growth is inadequate but where shelterwood cutting is too risky due to damaging agents such as rot and wind. Balsam fir is reproduced on these small areas by natural seeding from the bordering uncut stand.

Clearcut strips are well suited for fir stands with uniform structure and stocking, whereas small patches are better suited for nonuniform stands. Strips may be arranged either as alternate strips or as progressive strips in sets of three. On cool, moist sites where maximum shading is not necessary to establish fir seedlings, fairly wide strips are recommended to reduce harvesting costs. Strips that are perpendicular to, and progress toward, the prevailing wind direction—generally from the western quadrant (NW-SW) in the Lake States—should maximize seed dispersal and minimize wind damage. Based on balsam fir's seeding distance (see p. 8), strips can be up to 3 chains (1 chain = 66 feet) wide with seeding from both sides or 2 chains wide with seeding only from the windward side. These distances can also be used to determine the width of small patches or of subsequent enlargements.

On hot, dry sites where shelter is necessary for seedling establishment, strips should be: (1) no wider than half the stand height and (2) oriented east-west, with subsequent strips progressing southward. Narrow strips are also recommended for the last set of either alternate or progressive strips. This set tends to reproduce poorly because removing it usually eliminates all (or most) of the nearby seed source. To minimize the area receiving limited seeding, strips in the last set should be as narrow as possible and yet wide enough for the trees to be windfirm; strips about 1 chain wide are suggested.



Figure 3.—*This balsam fir understory developed following partial cutting of a mixed stand about 15 years ago. Such advance growth is typical in stands partially opened by harvesting or other disturbance.*

Balsam fir seedlings generally are well developed and well stocked where mature stands have been partially opened (fig. 3). Hence shelterwood cutting is most appropriate where fir advance growth is inadequate. Unfortunately, mature balsam fir often is vulnerable to serious wind damage after a stand is partially cut. Thus, the shelterwood system should be used only on areas or sites where fir is known to be windfirm.

When using the shelterwood system, a two-stage cutting is suggested in which trees are removed either in strips or uniformly throughout the stand. The first stage—either a preparatory or seed cutting—should leave a crown cover of about 60 percent and not remove more than 40 percent of the basal area. This opens the stand enough to favor fir reproduction without risking major problems from wind and competing vegetation. The least desirable trees should be removed, leaving uniformly spaced dominant and codominant trees of balsam fir and other desirable species. Residual trees should be selected for good seed production, windfirmness, and timber quality. In some stands thick duff or a heavy slash

cover hinders seedling establishment following the first cutting, so scarification or slash disposal may be needed to improve seedbeds.

The second stage or final cutting should be made as soon as both the stocking and development of fir reproduction are adequate (see p. 9 and 10). Harvesting and other operations must be done carefully, of course, to avoid damaging either residual trees or reproduction (see p. 18).

The selection system should be used to manage balsam fir in uneven-aged stands. However, as indicated earlier, uneven-aged stands are appropriate mainly for special purposes and on certain sites. The information in the next paragraph should be considered carefully before deciding whether to make selection cuttings in a particular stand.

Under the selection system it is necessary to develop and maintain a balanced distribution of size (or age) classes with decreasing numbers of trees as the d.b.h. classes increase. This requires periodic cuttings to remove trees in a variety of size classes. Each operation is a combined harvest of the largest trees and a thinning or other intermediate treatment of the smaller trees. The selection system should be limited to good-quality stands that are windfirm and have mixed age and size classes, whereas the clearcutting or shelterwood system is recommended to rehabilitate highgraded or otherwise degenerate stands. The selection system is especially appropriate on wet-mesic sites because uneven-aged fir stands are easy to maintain on these sites. However, with frequent cuttings, the selection system can probably succeed on a variety of sites.

When using the selection system, different cutting intervals (years between cuttings) and residual basal areas are recommended depending on the management intensity that can be practiced. Although the cutting interval may vary as stand or other conditions change, guidelines from the Northeastern States for spruce-balsam fir stands are as follows (Frank and Blum 1978):

Management intensity	Cutting interval	Residual basal area
	(Years)	(Square feet/acre)
Intensive	5	115
	10	100
Extensive	20	80

Three or more cuttings are usually needed to convert an unmanaged forest to a selection forest because it takes time to develop a balanced distribution of size classes, especially when each cutting must be fairly light to control wind damage. Remove no more than 30 percent of the basal area at one time. For satisfactory development of balsam fir reproduction, make openings larger than those created by removing a single mature tree. However, to control less tolerant species, the diameter of openings should not exceed the stand height. Some old trees may have to be kept in the beginning, but eventually none should be grown more than about 10 years beyond the "quality" rotations given on page 6. Also, because repeated cuttings are required, it is critical to minimize logging damage (see p. 18).

Windfirmness of the residual trees should be given top priority when marking a balsam fir stand for selection cutting. To make optimum use of growing space, leave crop trees or potential crop trees as evenly distributed as possible. In previously unmanaged stands high-risk and low-quality trees usually comprise the bulk of the material removed initially, but the percentage of such trees diminishes with succeeding harvests. Generally, the marking priority is: (1) high-risk trees likely to die before next harvest, (2) low-quality trees, (3) slow-growing trees, (4) trees of less desirable species, (5) trees whose removal will improve spacing, and (6) mature trees with desirable characteristics.

Conversion and Alternating Crops

The main purpose of this handbook is to present information on how to manage the balsam fir type. Often, however, balsam fir will not fulfill the owner's objective as well as some other forest type. Also, fir commonly occupies sites better suited for other types, and it is sometimes severely damaged by the spruce budworm. In such cases the manager may need to consider converting balsam fir to, or alternating it with, another forest type or tree species.

What type to convert to or alternate with—as well as when and how—usually depends on several interrelated factors: management objective, soil-site conditions, species composition, spruce budworm hazard, successional stage, and merchantability. Of course, the management objective should be realistic both biologically and economically. Depending on site and stand conditions, balsam fir can be converted to or alternated with one or more other types or species. Aspen, paper birch, red pine, eastern white pine, and white spruce can be grown on a fairly wide range of sites. Of other associated types, jack pine is best suited to dry sites, northern hardwoods to mesic sites, and black spruce and northern white-cedar to wet sites.

Depending on the factors mentioned above, conversion can be either natural or artificial, prompt or

gradual. Clearcutting a balsam fir stand that contains some aspen, for example, often results in prompt conversion to aspen by suckering. Or the manager can quickly convert to other conifers by planting after clearcutting. In contrast, selection cuttings in a fir stand that contains northern hardwoods may lead to gradual conversion to sugar maple and other tolerant hardwoods. The various options for converting to or alternating with other types or species should be considered in relation to both short- and long-term objectives. For example, prompt harvesting after a budworm outbreak to salvage fir pulpwood can be followed by planting a long-lived conifer to produce sawtimber.

The opportunities to convert balsam fir to, or alternate it with, other types are many and varied because fir grows under a wide range of conditions and its seedlings form an almost ubiquitous understory in many Lake States types. Only general guidelines on conversion and alternating crops are presented here. More detailed information on associated types is available in the following references:

Type name	Reference[9]
Hardwood types	
Aspen	Perala 1977
Paper birch	Safford 1983
Northern hardwoods	Tubbs 1977
Pine types	
Jack pine	Benzie 1977a
Red pine	Benzie 1977b
	Schone *et al.* 1984
Eastern white pine[10]	Lancaster and Leak 1978
Spruce-fir types	
Spruce-fir[11]	Flexner *et al.* 1983
	Frank and Bjorkbom 1973
White spruce[11]	Stiell 1976
Black spruce	Johnston 1977a
Northern white-cedar	Johnston 1977b
All types	Burns 1983[12]

Balsam fir and aspen often exist together and where they do it is difficult to manage one to the exclusion of the other. Balsam fir and paper birch are also commonly associated. Even if the main objective is to grow balsam fir timber, an aspen or birch component probably should be maintained for multiple-use purposes such as wildlife habitat and esthetics. In addition, aspen and birch are important in dealing with the spruce budworm. Some aspen should be present for easy conversion by suckering in case of an outbreak, and a birch overstory can significantly reduce fir mortality. However, if birch does not form an overstory, fir mortality may be severe and suddenly expose the birch, causing dieback and death.

On most sites balsam fir and aspen should be managed as alternating crops (fig. 4), whereas balsam fir and paper birch should be managed together. However, if high-quality logs of northern hardwoods, red pine, or white spruce can be grown on a site (aspen and paper birch site indexes 60 or more), the manager should consider conversion even though it may be costly.

In a mature stand of fir with some aspen (at least 18 square feet of basal area per acre), clearcut to produce a fully stocked stand of aspen suckers (fig. 4, left). If fir advance growth is sparse, harvest areas should be within 2 to 3 chains of seed-bearing firs (see p. 10). Once the aspen is mature and fir forms an understory (fig. 4, right), harvest the aspen to release the fir. Well-distributed openings in the fir stand will allow enough aspen suckers to develop so the cycle can be repeated when the fir matures.

Balsam fir also commonly forms an understory in paper birch stands. When the birch is mature, it can be harvested to release the fir, just as in aspen stands. To reduce spruce budworm losses, maintain some overstory birch (or aspen) by clearcutting progressive strips or small patches rather than large areas. Harvesting must be done carefully to leave an adequate stocking of fir (see p. 10 and 18). To ensure a birch component in the new stand, scarify the soil in scattered openings and leave seed-bearing birches within 3 chains. Once the fir matures, treat the stand as described below.

Where mature balsam fir has at least three to five paper birch seed trees per acre, clearcut the stand in progressive strips or small patches or use shelterwood cutting. Strips should be from 1 to 2 chains wide and patches 1 acre or less in size. Scarify about 50 percent of the harvest area to prepare favorable seedbeds for both fir and birch. Full-tree skidding with branches and tops intact prepares favorable seedbeds when the soil is not frozen or covered by snow. Seedling reproduction may be supplemented by vigorous stump sprouts if the birch is younger than 60 years. However, sprouts usually contribute no more than about 10 percent to birch stocking because many are eliminated by repeated deer browsing.

The future composition of the new stand can be controlled by releasing potential crop trees about 8 years after final harvest or when stand height averages from 6 to 10 feet. To obtain a mixed stand in

[9] *For full citations, see Appendix, p. 25.*

[10] *Includes eastern hemlock in Burns (1983).*

[11] *See eastern spruce-fir in Burns (1933).*

[12] *Provides up-to-date summaries.*



Figure 4.—*These views show the key steps in managing balsam fir and aspen as alternating crops: clearcut mature fir and associated aspen to produce aspen suckers (left); harvest mature aspen to release fir understory (right), preferably earlier than shown.*

which balsam fir is the dominant species, use the guidelines in the tabulation on page 7, except include the release of about 150 paper birch per acre.

Balsam fir is also commonly associated with northern hardwoods and may even be dominant for a while after disturbance. However, on fertile mesic sites (well-drained loams), fir does not compete well with long-lived shade-tolerant hardwoods such as sugar maple. On sites with a sugar maple site index of 55 or more, control fir advance growth in order to favor hardwood reproduction and clearcut mature fir if hardwood advance growth is adequately stocked. The minimum number per acre of well-spaced hardwoods should be 5,000 seedlings 3 to 4 feet tall or 1,000 saplings 2 to 4 inches in d.b.h. If such stocking is lacking, remove the fir in two or more stages—by shelterwood cutting, for example—so the hardwoods can become established or better stocked.

On less well-drained hardwood sites (sugar maple site index less than 55), balsam fir should be managed along with its associated hardwoods. These include yellow birch—plus eastern hemlock in Michigan and Wisconsin—on somewhat poorly drained sites and black ash and red maple on poorly drained sites. To grow only pulpwood, reproduce all species when the fir is mature (about age 50); use clearcutting where fir advance growth is adequately stocked and shelterwood cutting where it is not. To grow both pulpwood and hardwood saw logs, clean or thin young stands to obtain the desired proportions of fir and hardwoods. Then harvest the fir at about age 50 and leave the hardwoods until they mature (roughly age 100). Depending on how much the stand is opened, fir may produce a second crop of pulpwood while the hardwoods develop into sawtimber. When the hardwoods are mature, reproduce all species as described above and repeat the process. Because of balsam fir's shade tolerance, selection cutting is suitable where a high proportion of fir is desired.

Converting balsam fir to other conifers should be considered where aspen and paper birch site indexes are less than 60 and northern hardwoods are not aggressive. Balsam fir sometimes grows on dry to dry-mesic sites, especially as an understory of jack or red pine. However, these sites (usually sandy soils) are better suited for pine, with red pine outproducing jack pine except on extremely dry sites. In most cases the manager should eliminate fir when harvesting pine and convert jack pine to red pine.

Balsam fir is a common associate of eastern white pine on mesic to wet-mesic sites. Fir—either pure or mixed with eastern hemlock—often forms an understory in mature white pine stands. This understory may improve wildlife habitat or esthetics, but usually it should be removed so white pine or another preferred conifer can be established. White pine can be reproduced naturally by shelterwood cutting or artificially by clearcutting and planting. Blister rust-resistant stock is now available for areas where white pine blister rust is a major problem. To convert to another conifer, red pine should be planted on the drier, less fertile sites and white spruce on the moister, more fertile sites.

White spruce is generally a minor associate in balsam fir stands on mesic to wet-mesic sites. However, because of its higher value, longer life, and greater tolerance of budworm defoliation, white spruce is usually preferred over balsam fir. Common objectives are to increase the stocking of white spruce and

to manage for spruce sawtimber. If a mature fir stand has more than 500 well-distributed white spruce 3 feet or taller per acre, clearcut the stand to release them but use care to minimize logging damage (see p. 18). If white spruce advance growth is inadequate, either use shelterwood cutting and scarification to obtain natural reproduction or clearcut the stand and plant white spruce.

As the new stand develops, intermediate treatments will be needed to favor white spruce over balsam fir or other species. To produce a stand of spruce sawtimber, release—by cleaning, for example—200 to 300 white spruce crop trees per acre during the sapling stage. Then, in the pole stage thin the surrounding trees one or more times to keep the spruce crop trees dominant. Because white spruce sawtimber requires a rotation of 80 to 100 years, most or all of the shorter-lived fir and other species should be removed before the final harvest.

As indicated earlier, balsam fir often grows on wet-mesic to wet sites, especially in mixed swamp conifer stands that contain northern white-cedar and black spruce. Although the pulpwood produced by balsam fir sometimes makes these stands more attractive economically, fir is not well adapted to wet sites (mainly organic soils). In addition, balsam fir usually is not as valuable for wildlife habitat (particularly deeryards) as northern white-cedar. Unfortunately, balsam fir often dominates the advance growth in mixed swamp conifer stands, so it commonly succeeds northern white-cedar and black spruce after harvesting or other disturbance.

In most cases the manager should minimize the balsam fir component on wet sites and favor associated swamp conifers. On harvest areas broadcast burning of slash simultaneously eliminates fir advance growth and improves seedbeds for associated conifers. Usually northern white-cedar or tamarack should be reproduced on the more productive sites and black spruce on the less productive sites.

Controlling Damaging Agents

Spruce Budworm

The spruce budworm is the most serious pest of balsam fir in the Lake States. Recurring outbreaks have caused much growth loss and mortality. In addition, severe defoliation by the budworm often leads to attack by other insects and rot fungi. Thus, the spruce budworm is the most damaging agent of balsam fir in the Lake States.

High mortality of balsam fir from the spruce budworm is most likely in fir stands with the following characteristics:[13]

1. high basal area or percentage of stand (50 percent or more) in balsam fir and/or white spruce;
2. mature stands (50 or more years old), especially if extensive;
3. open stands with tops of balsam fir and/or white spruce protruding above canopy;
4. stands on poorly drained soils that are extremely wet or dry; and
5. stands downwind of a budworm outbreak.

Hazard-rating systems are available for assessing the vulnerability of balsam fir to budworm-caused mortality. These systems help the manager make either short-term decisions during a budworm outbreak to minimize present losses or long-term decisions between outbreaks to reduce future losses. Short-term rating systems can help the manager decide which stands to harvest or spray during the next few years. These systems require technical procedures and so are used mainly by pest management specialists. For detailed information on short-term rating systems, consult Agriculture Handbook 636 (Witter and Lynch 1985).

Long-term rating systems help the manager set priorities and schedules for harvesting or other treatments to reduce the vulnerability of fir stands. These systems are based on stand vulnerability, which has been related to different stand characteristics in different geographic regions of the Lake States. Separate, region-specific systems must be used to reliably estimate the potential loss of balsam fir from a budworm outbreak. Long-term rating systems have been developed for Minnesota and Michigan's Upper Peninsula but not for Wisconsin.

Both the Minnesota and Michigan systems are easy to use because they utilize readily available (or easily obtainable) stand data and simple computations. Routine compartment examinations or inventories usually provide the necessary data. To use the Minnesota system, for example, the manager only has to determine the preoutbreak basal area of balsam fir and the percent of stand basal area in nonhost species (those other than fir or spruce). Agriculture Handbook 636 (Witter and Lynch 1985) should be consulted for the procedures and tables needed to use the Minnesota and Michigan systems. Unfortunately, these systems are region-specific and thus probably are not applicable elsewhere; for example,

[13] *Adapted from Witter and Lynch (1985).*

tests indicate the Minnesota system is unreliable in Wisconsin. Another precaution is that the Michigan system is not applicable on wet sites with organic soils.

How to handle the spruce budworm problem—especially over large areas and long time periods—is a complex and somewhat controversial subject. However, a few principles regarding the budworm and its control apply to most situations. The manager should consider the following principles carefully before undertaking specific practices:

1. A strong interdependence has apparently evolved between the spruce budworm and balsam fir forests. Thus, budworm control and fir management are practically inseparable.
2. The continuing underutilization of balsam fir ensures a buildup of mature and overmature fir stands, which are highly vulnerable to budworm damage. Therefore, increased utilization that diversifies the age class distribution of future fir stands is needed to obtain long-term budworm control.
3. Both major types of budworm control—insecticidal and silvicultural—have limitations. A combination usually provides a better overall control program than either type alone.
4. Specific practices to control the budworm depend not only on stand characteristics but also on the management intensity that is feasible. Intensive management offers a good opportunity to reduce the probability of an outbreak and to minimize economic loss if an outbreak occurs.

During a spruce budworm outbreak the manager should consider three alternatives for handling high-hazard stands: (1) harvest as much fir as possible before serious losses occur; (2) if harvesting cannot keep pace, spray high-value stands with insecticides until they can be harvested; and (3) abandon low-value stands. When stands have a similar hazard rating, various stand characteristics can be used to further rank harvesting or spraying priorities. Stands on extremely wet or dry sites usually are more vulnerable to budworm damage than those on good sites. However, it is economically better to give higher priority to stands on good sites. If sites are similar, stands with more balsam fir should be harvested first because they have more potential for mortality. Also, stands 50 years or older should be harvested before those younger than 50 years, especially if top-kill or mortality is already present. To obtain the greatest economic return, harvest stands with the highest volume of undecayed wood. The amount of fir actually harvested or sprayed will depend on the management intensity that is economically feasible.

Once a budworm outbreak has developed, balsam fir trees begin to die after 3 to 5 consecutive years of severe defoliation. Dead fir usually remains usable for 1 to 3 years, depending on local differences in decay rates. Generally, merchantable fir stands should be harvested as rapidly as possible to salvage damaged, dying, and dead trees. Even if fir advance growth is inadequate, the stand should be clearcut if either budworm-caused top-kill and/or mortality is present or rot and/or wind is a major problem (see next section). Where fir advance growth is adequate (see p. 9), a new fir stand likely will develop after clearcutting; otherwise consider converting to or alternating with another forest type or tree species (see p. 11). Presalvage cutting is appropriate if the owner wants to maintain fir and inadequate advance growth is the only unfavorable stand condition. Such cutting removes highly vulnerable trees in anticipation of damage but leaves some balsam fir for a seed source.

Even young fir stands that develop after harvesting may be damaged by the spruce budworm. To control the budworm in these stands, fell all overstory host trees—white spruce, black spruce, and balsam fir—as soon as adequate fir reproduction is established. This is necessary because these residual trees commonly support budworm populations and can serve as infestation centers for future outbreaks.

Insecticide spraying is used mainly in mature or nearly mature, high-value stands to keep balsam fir alive until it can be harvested. Spraying is recommended in mature stands that have been severely defoliated for 2 consecutive years and cannot be harvested within 5 years. Spraying may also be used to suppress budworm populations before defoliation becomes severe. Conditions are suitable for spraying when fir and spruce buds have broken, needles are beginning to spread out and elongate, and most budworm larvae are in their fourth instar. These conditions usually occur by late May or early June in the Lake States.

Various chemical and microbial insecticides are currently registered for spruce budworm control. Carbaryl (Sevin 4-Oil) is the most commonly applied insecticide; other common ones include acephate (Orthene), *Bacillus thuringiensis* (Dipel and Thuricide), and trichlorfon (Dylox). Some of these insecticides differ substantially in their characteristics; also, the list of registered insecticides and their

labels are subject to change. Therefore, consult a pest management specialist to find out the latest recommended treatment for the situation. Insecticide spraying should be done carefully, following all pertinent precautions and regulations (see Pesticide Precautionary Statement, p. 27).

The future management of low-value fir stands abandoned during a spruce budworm outbreak depends on such factors as species composition, soil-site conditions, and the owner's objective. Death of the overstory fir commonly releases fir advance growth, allowing it to develop into a new stand. Death of the fir may also offer a good opportunity to change to another forest type as discussed under "Conversion and Alternating Crops" (p. 11) (fig. 5).

Between outbreaks the manager should undertake long-term measures or strategies to reduce future budworm losses. Probably the best measure is to increase the amount of nonhost species. Harvesting often offers a good opportunity to change a predominantly fir stand to a mixed stand or another type (see p. 11). When economically feasible, intermediate treatments such as release or cleaning can be used to produce mixed stands of fir and hardwoods or fir and other conifers (see p. 6). For maximum effectiveness in reducing future budworm losses, these various operations should be spatially arranged so as to break up large areas dominated by fir.

Although mixed stands may reduce future budworm losses, they also reduce the yield of balsam fir—at least in the short run. This is especially true where fir is overtopped by other species such as hardwoods. The manager should weigh the benefits of increased fir growth after release, for example, against the potential losses from a budworm outbreak. If harvesting or insecticide spraying can be prompt after an outbreak begins, release or other intermediate treatments will increase fir yield. If prompt action is doubtful, it is safer to manage fir in mixed stands.

Other long-term measures that should help reduce future budworm losses are to diversify the age class distribution of balsam fir stands and to shorten the rotation. Utilization that equals, or temporarily exceeds, annual growth will often be needed to eliminate the buildup of mature and overmature fir that exists in many areas. Unless the objective is to produce small saw logs, harvest fir stands as soon as possible where they exceed the "quality" rotations given on page 6. When economically feasible, thin dense young stands; this not only shortens their rotation (see p 8) but also keeps them vigorous and probably less vulnerable to budworm damage.



Figure 5.—*Typical stand of balsam fir killed by the spruce budworm and now dominated by red raspberry. The lack of reproduction offers a good opportunity to convert—by planting—to another conifer.*

Rot and Wind

Trunk rot and root (or butt) rot are the two major types of decay found in living balsam fir trees. The principal trunk-rot fungus is red heart rot, which causes two or three times more cull than root-rot fungi. The economically important root-rot fungi include four white (or yellow) stringy rots and two brown cubical rots (see Appendix, p. 25, for scientific names). Shoestring root rot, a white stringy rot, is probably the most prevalent species. Root rots damage fir mainly by making the tree susceptible to windthrow or windbreakage; they also kill the tree directly (especially shoestring root rot), cause cull by extending into the trunk, and reduce growth.

Red heart rot enters balsam fir trees through fresh wounds such as broken tops or branches and trunk injuries. These wounds are commonly caused by harvesting and snow or ice storms; black bears sometimes wound trunks by stripping the bark. Root (or butt) rots enter balsam fir through root or basal wounds caused by harvesting and various natural phenomena. Shoestring root rot invades fir especially during droughts and following severe defoliation by the spruce budworm.

Except for woodpecker holes, few reliable external indicators of trunk and root rot exist for balsam fir. Old wounds probably indicate the presence of rot, but the causal fungi rarely produce fruiting bodies

on living trees; in addition, the important shoestring root rot mainly develops below ground. However, as discussed under "Rotation" (p. 5), stand age and site conditions strongly influence the presence of rot. Therefore, in most cases, the "quality" rotations given there will minimize losses from rot; they may also help reduce future budworm losses. Even shorter rotations should be considered for stands vulnerable to rot because of severe budworm defoliation or other significant damage.

Other ways to control losses from rot include growing balsam fir on suitable sites, releasing fir advance growth, minimizing damage from mechanized operations, and monitoring budworm or other damage. In general, manage fir on wet-mesic sites where it grows well and has less rot than on dry sandy sites or on highly productive (mesic) hardwood sites. Release not only increases the growth rate but also apparently can reduce the incidence of rot. However, if fir advance growth is severely suppressed (especially by northern hardwoods), do not release or otherwise manage it for timber. Mechanized equipment must be used carefully to minimize wounding of residual firs (see next section). This is particularly important if the rotation is lengthened in order to produce saw logs. Fir stands that have suffered from budworm defoliation, drought, or storm damage should be checked periodically. If losses from rot begin or appear imminent, reproduce the stand by using an appropriate silvicultural system (see p. 9).

As already indicated, wind commonly uproots or breaks off balsam fir trees weakened by root (or butt) rot. Wind also uproots balsam fir because of its shallow root system. This often occurs where the rooting zone is shallow, such as on sites with a high water table or a fragipan. Moderate windstorms blow down some trees—such as those weakened by rot—and leave them lying crisscrossed, whereas severe windstorms generally blow down all trees in an area and leave them lying parallel to each other. Wind damage is usually increased by partial cutting—especially in stands not previously managed, in stands with considerable root (or butt) rot, and on sites with a shallow rooting zone.

Wind damage to balsam fir can be controlled by good management. To minimize losses from wind and rot combined, use the "quality" rotations given on page 6. Do partial cutting such as thinning and shelterwood cutting only on areas or sites where fir is known to be windfirm. If wind is a major problem, manage fir extensively—for example, do nothing except clearcut when mature—or do not manage for fir at all.

When setting up a fir stand for partial cutting, make sure the windward side is protected by a zone of uncut timber at least 1 chain wide. Also, make the cutting boundary smooth and reasonably straight to avoid wind damage resulting from sharp angles such as corners. In mixed stands of fir and hardwoods, leave a well-distributed hardwood component. For other ways to control wind damage when doing partial cutting, see "Intermediate Treatments" (p. 6) and "Silvicultural Systems" (p. 9). If damage—which occurs especially during the first 3 to 5 years after cutting—becomes severe, consider a salvage operation to minimize the timber loss.

Other Agents

Although the spruce budworm is the predominant insect damaging balsam fir (including cone crops) in the Lake States, a few other insects can become important pests. Outbreaks of two defoliators, the hemlock looper and the eastern blackheaded budworm, have seriously damaged mature and overmature stands dominated by fir. Two secondary insects, the balsam fir bark beetle and the balsam fir sawyer, often attack fir weakened by the spruce budworm or drought. The fir coneworm commonly attacks fir cones and may cause significant seed loss. Diversifying the age class distribution of balsam fir stands and shortening the rotation—as discussed under "Spruce Budworm" (p. 14)—should reduce damage by the defoliators; control of the spruce budworm should reduce damage by the secondary insects. No silvicultural measures are known for controlling the coneworm.

Balsam fir is host to many rusts, cankers, and other diseases, including a conspicuous yellow witches' broom. But none except rots (see p. 16) is economically important, so control measures are not needed.

Wildlife sometimes damages balsam fir by feeding or other activities. For example, moose, white-tailed deer, and snowshoe hares browse reproduction; mice and voles feed on bark of reproduction; black bears strip bark of mature trees; birds (such as spruce grouse) and red squirrels nip buds; and mice, voles, and birds consume seed. It is fortunate these activities usually do not severely damage fir because no practical control measures are known. Actually, as long as balsam fir stands can be established or maintained, these activities should be considered beneficial to wildlife rather than damaging to fir.

Because of its thin bark and shallow root system, balsam fir is susceptible to damage from harvesting and other mechanized operations. Residual trees often develop rot from wounds to their base or roots

(see p. 16), and advance growth commonly is crushed by equipment or buried by slash. Hence treatments that involve keeping residual trees or advance growth—for example, thinning or shelterwood cutting—should be done carefully by skilled operators using small, maneuverable equipment. Ideally, such treatments should be done in winter when the base and roots of trees, and the stems of small advance growth, are protected by a snow pack. Full-tree skidding is recommended if a heavy slash cover is likely; however, skidding damage needs to be controlled by following the above precautions.

To release balsam fir from large cull hardwoods, use herbicide injection rather than felling to kill the hardwoods (see p. 7). This not only minimizes damage to the fir but also provides standing dead trees for cavity-nesting wildlife.

Balsam fir trees of all sizes are easily killed by fire because of their thin resinous bark, shallow root system, and flammable needles, which often are close to the ground. However, good fire protection now results in little loss, and much of the fir type grows on wet-mesic to wet sites where wildfire risk is normally low. Heavy cutting, of course, produces large amounts of balsam fir slash, which can be a fire hazard for several years. Therefore, use full-tree skidding if a heavy slash cover is likely, such as after shelterwood cutting or clearcutting.

OTHER RESOURCE CONSIDERATIONS

Boughs and Christmas Trees

Compared to timber production, balsam fir boughs and Christmas trees are minor products of natural stands. However, large quantities of boughs (for making wreaths) and many Christmas trees are harvested in certain areas of the northern Lake States. Prolonged needle retention, color, and pleasant fragrance are characteristics that make balsam fir attractive for these uses.

Boughs are cut from the lower branches of open-grown trees or from trees felled for pulpwood. Christmas trees include large ones (20 to 60 feet tall) for community use as well as small ones for home use. The large trees must be open-grown, as occurs when sparse fir reproduction develops after heavy cutting. Some small firs are harvested from natural reproduction, but shearing is needed to make them competitive with sheared, plantation-grown trees.

The potential for producing more balsam fir Christmas trees by shearing natural reproduction appears good on small, privately owned areas and on power line rights-of-way. However, little is known about the spacing and other cultural requirements to grow marketable trees. Forest managers probably can obtain some advice from Christmas tree growers experienced with balsam fir. A potentially serious pest is the balsam gall midge, which forms galls on the needles of young, open-grown firs. The infested needles drop prematurely and make the trees unmarketable. If this insect becomes a problem, consult a pest management specialist for the most appropriate treatment.

Wildlife Habitat

The balsam fir type is important to many wildlife species in the northern Lake States. The timber wolf, an endangered species (threatened in Minnesota), and four species with sensitive habitat needs—pine marten, fisher, Canada lynx, and bobcat—are all associated with this type. Other species that use the balsam fir type for part or all of their habitat needs include: common mammals such as white-tailed deer, moose, black bear, snowshoe hare, and small rodents (for example, red-backed vole, deer mouse, and red squirrel); various birds, especially spruce grouse, warblers, and three-toed woodpeckers; and a few reptiles and amphibians, particularly salamanders and frogs.

Balsam fir stands are beneficial for both "edge" and "interior" wildlife species. Although edge species (such as deer and hare) are associated mainly with forest openings and young stands, they often use middle-aged or mature fir stands for protection from weather or predators (fig. 6). Interior species (such as marten and warblers) use mature fir stands for most or all of their habitat needs. The best way to manage balsam fir stands for wildlife depends on the species the forest owner wants to favor. If a diversity of species is desired, various stand conditions must be maintained. This is most feasible on large (especially public) forests.

The balsam fir type protects several wildlife species from winter temperatures and snow. Although not as beneficial as northern white-cedar or eastern hemlock for deeryards, balsam fir is important because it is more widespread and easier to establish than white-cedar or hemlock. Compared to white spruce, balsam fir generally has few branches near the ground; thus, deer can bed down closer to a fir tree and be less exposed to heat loss. Fir stands

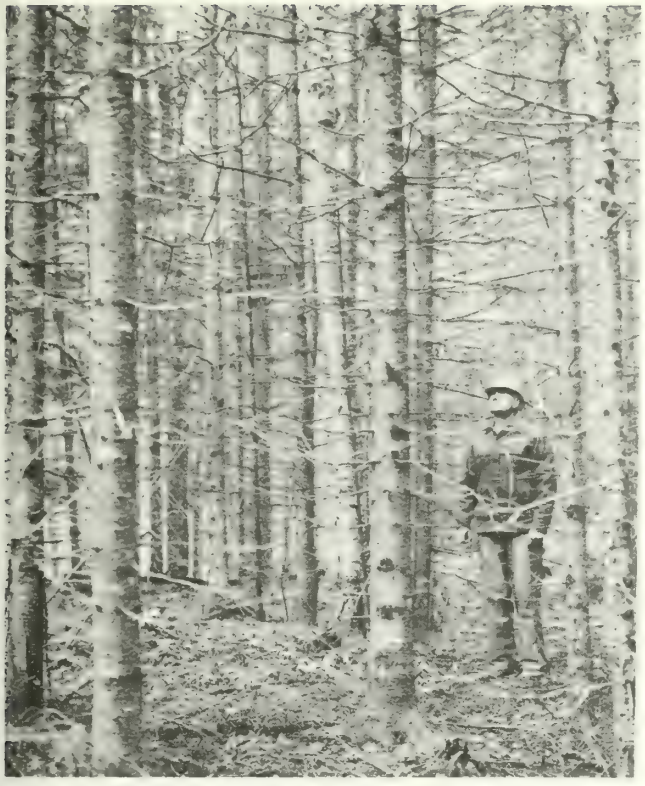


Figure 6.—*This closed stand of pole-sized balsam fir provides important habitat for several wildlife species. Such stands often are used for protection from weather, both in winter and summer.*

more than 20 years old with a basal area of at least 70 square feet per acre moderate temperatures. Also, snow is not as deep in balsam fir stands as it is in aspen and paper birch stands. Consequently, fir stands often are heavily used by deer and by moose with calves during the severe winter months. For similar reasons, deer and furbearers (such as fisher, lynx, and marten) use fir stands for travel lanes.

Edge wildlife species benefit most from balsam fir when stands suitable for winter cover occur adjacent to young (especially hardwood) stands, which produce browse or other food. For good deer and moose cover, manage fir in even-aged stands and maintain a closed canopy. If cover is critical, avoid heavy partial cutting and try to prevent severe budworm defoliation. A well-developed fir understory beneath mature aspen or paper birch also provides winter cover, especially in areas without adequate white-cedar or hemlock stands.

Other habitat important to deer and moose—and also used by hare—is poorly to moderately stocked or patchy pole- and sawtimber-sized fir stands. These lower density stands (with a basal area of less than 70 square feet per acre) support a well-developed shrub layer that provides food in close proximity to conifer cover. Converting such stands to spruce or pine plantations—especially using herbicides to control shrubs and hardwoods—greatly reduces the use of these areas not only by deer, moose, and hare but also by their predators such as the wolf, lynx, and fisher. Extensive areas of fir mixed with hardwoods are utilized especially by the bobcat and fisher.

During the warm summer months balsam fir stands provide shade that helps cool deer, moose, and bear after feeding in open areas. Moose commonly rest in fir stands near wetlands where they feed. To provide cooling sites for these and other wildlife species, leave from 2- to 5-acre patches of well-stocked balsam fir distributed throughout large harvest areas. Unfortunately, these patches can sustain spruce budworm infestations and should not be left where budworm control is a more important consideration. Also during summer various birds use fir stands for nesting; warblers such as the Cape May, blackpoll, and blackburnian especially prefer this habitat.

Another value of balsam fir for several wildlife species is protection from predators. Species such as marten, hare, songbirds, and even deer will use well-stocked fir stands for protection. Balsam fir also benefits certain predators; for example, single fir trees left on harvest areas provide perches for hunting and roosting hawks and owls. However, residual firs (or spruces) should not be left because they are too vulnerable to wind damage and can serve as infestation centers for budworm outbreaks (see p.15).

Many wildlife species feed on balsam fir (see p. 17), but only a few use it to much extent. Fir needles and buds make up a major portion of the spruce grouse's diet. Fir browse may form up to 30 percent of the moose's fall and winter diet; however, the average is much lower. In addition, fir stands attacked by the spruce budworm attract many insect-eating birds, especially Cape May, black-throated green, and blackburnian warblers, and woodpeckers such as the rare black-backed three-toed and northern three-toed. Woodpeckers, in turn, produce tree cavities that are used by various wildlife species, thus enhancing the value of the balsam fir type. On harvest areas slash supports insects eaten by birds such as the dark-eyed junco and winter wren. However, some slash should be removed in heavily cut stands to favor fir reproduction and reduce the fire hazard (see p. 9).

To benefit a diversity of wildlife species in the northern Lake States, maintain from 10 to 20 per-

cent of each management area (such as a compartment) in balsam fir stands. If conifer cover is lacking, promote succession to fir on enough of the area to achieve the recommended range. If fir stands occupy much more than 20 percent of an area, convert some of the area to other types, especially hardwoods (see p. 11). Converting excessive fir acreage to aspen would most benefit edge species, which include major game species such as white-tailed deer and ruffed grouse. Maintaining a moderate—rather than large—proportion of fir should not only enhance wildlife habitat (and esthetics) but also reduce vulnerability to budworm damage.

To manage balsam fir stands for a diversity of wildlife species, maintain a range of age (or size) classes from young seedlings to mature trees. Although this range can be obtained in uneven-aged stands, even-aged stands are preferred for wildlife (as well as timber) management in the Lake States. Depending on the food and cover needs in an area, fir stands should range from poorly to well stocked and from pure fir to half hardwoods. When harvesting fir stands, use small patches (from 1 to 5 acres) to favor edge species and large patches (from 10 to 40 acres) to favor moose and interior species. On larger harvest areas it is important to leave patches of well-stocked balsam fir for cover. These patches should be well distributed, from 2 to 5 acres in size, and total about 5 percent of each harvest area. However, as mentioned earlier, such patches should not be left where budworm control is a more important consideration.

Esthetics

Large stands of balsam fir—especially when pure and dense—have little esthetic appeal. But smaller stands (less than 100 acres) diversify the landscape, particularly when they are interspersed in extensive hardwood forests. Balsam fir stands mixed with hardwoods such as quaking aspen, paper birch, and red maple provide an attractive variety of tree forms and foliage colors. In addition, fir stands have a distinctive fragrance that recreationists enjoy and understory firs sometimes form a screen along roads.

To improve the esthetic appeal of large, mature fir stands, make small- or medium-sized openings (less than 40 acres) by clearcutting or shelterwood cutting; for best results, locate these openings so they create scenic vistas. To enhance the esthetic appeal of small fir stands, thin those that are densely stocked to produce larger trees or use selection cutting to develop a variety of tree sizes. To make both large and small stands more attractive, develop mixtures of fir and hardwoods during intermediate treatments or when the stands are reproduced. If present, favor hardwoods—particularly the maples and paper birch—on exposed locations such as ridges and hilltops.

To minimize the impact of harvesting on the esthetic appeal of the balsam fir type, the manager should: (1) have harvest boundaries follow natural site or forest type lines and (2) remove heavy slash cover or other debris to leave harvest areas neat. In heavily cut stands easily visible to the public, remove slash by full-tree skidding and burn it at the landing. Keep landings from becoming eyesores by locating them in inconspicuous places and by burning all slash piles.

Water

Balsam fir stands have higher evapotranspiration rates than hardwood stands, and dense fir stands intercept more precipitation than pine stands. This means water yield for streamflow is less from fir stands than from hardwood stands and slightly less from dense fir stands than from pine stands. Thus, the manager should consider converting fir to hardwoods—or even to pines—if higher water production is a major objective. Water yield from the fir type can be increased somewhat, of course, by any type of cutting or other treatment that opens dense stands.

Clearcut areas up to at least 40 acres should have no detrimental effect on water quality provided they are well distributed and have skid and haul roads laid out carefully to protect against soil erosion. Also, aerial spraying of pesticides should cause no serious hazard to water quality if all pertinent precautions and regulations are followed (see Pesticide Precautionary Statement, p. 27). It is particularly important not to contaminate open water with pesticide, so do not spray vegetation bordering ponds, lakes, and watercourses.

Balsam fir is desired along trout streams because its shade keeps the water cool and few trees are felled by beaver for dam building. Where fir predominates, not only is shade maintained but also beaver dams—which reduce the quality of trout streams—are infrequent.

APPENDIX

Yield and Growth

Tables are limited for determining the present yield and future growth of balsam fir stands in the Lake States. The only ones available that give yield and growth by site index are for mixed stands of spruce and fir (tables 1 and 2). However, these tables can be used to obtain quick, rough estimates for pure fir stands. One table gives the yield and growth of fully stocked (normal), even-aged stands (table 1); and the other gives the yield of variously stocked, uneven-aged stands (table 2).

A microcomputer program called TWIGS is recommended for obtaining more detailed information on the yield and growth of balsam fir stands. The program not only can be used for fir stands of any age structure or species combination, but also it provides additional information on management and economics. TWIGS is briefly described later in this section.

Table 1.—*Yield and growth per acre of fully stocked, even-aged spruce-balsam fir stands by site index and total age*[1]

Total age	Heights of dominants	Trees 1 inch d.b.h. and larger					Trees 4 inches d.b.h. and larger	
		Average d.b.h.	Number	Basal area	Volume[2]	Growth[2]	Volume[2]	Growth[2]
Years	*Feet*	*Inches*		*Square feet*	*Cubic feet*		*Cords*	
SITE INDEX 60								
30	36	3.3	1,550	110	—	—	—	0.9
40	48	4.7	1,020	135	1,020	106	13	1.1
50	60	5.5	820	145	2,040	74	22	.8
60	66	5.8	780	150	2,580	41	28	.4
70	70	6.0	750	155	2,920	30	32	.3
80	73	6.2	740	160	3,200	22	34	.2
SITE INDEX 50								
30	30	2.8	2,050	110	—	—	—	—
40	41	4.1	1,350	130	920	95	12	1.0
50	50	4.8	1,100	145	1,860	70	21	.7
60	55	5.1	1,020	150	2,400	39	27	.4
70	58	5.3	990	155	2,700	28	30	.2
80	60	5.4	980	155	2,930	21	32	.2
SITE INDEX 40								
30	24	2.5	2,650	110	—	—	—	—
40	33	3.5	1,750	130	780	72	11	0.9
50	40	4.1	1,420	140	1,580	60	19	.7
60	44	4.3	1,320	150	2,000	33	24	.4
70	46	4.5	1,270	150	2,270	34	26	.2
80	48	4.6	1,260	155	2,490	19	28	.1
SITE INDEX 30								
30	18	2.1	3,450	100	—	—	—	—
40	24	2.9	2,250	120	500	48	7	0.6
50	30	3.4	1,800	135	1,010	38	12	.4
60	33	3.6	1,700	140	1,290	22	16	.2
70	35	3.7	1,650	145	1,460	16	18	.1
80	36	3.8	1,620	145	1,590	12	19	.1

[1] *Values adapted from Bowman (1944) and based on data from northern Michigan and northeastern Minnesota.*
[2] *Merchantable volume and periodic annual growth of peeled wood*

Table 2.—*Yield per acre 10 years after measurement for uneven-aged spruce-balsam fir stands by site index and basal area*[1]

Basal area per acre	Site index[2] 30	40	50	60	Site index[2] 30	40	50	60
Square feet	------ *Cubic feet*[3] ------				----- *Cords*[3] -----			
40	290	540	670	780	3	6	8	9
60	530	900	1,150	1,280	6	11	14	15
80	870	1,400	1,730	1,840	10	16	20	22
100	1,280	1,990	2,420	2,700	15	23	28	32
120	1,640	2,400	2,840	3,180	19	28	34	38
140	--	2,660	3,080	3,420	--	31	36	40

[1] *Values adapted from Bowman (1944) and based on data from northern Michigan and northeastern Minnesota.*

[2] *See section below for precautions and guidelines on estimating site index in uneven-aged stands.*

[3] *Merchantable volume of peeled wood.*

Site Index

An estimate of balsam fir site index is needed to use either the tables or TWIGS. The best estimate is obtained using the total height and total age of uninjured dominant and codominant firs that are at least 20 years old and have never been suppressed. Site index curves (fig. 7) are convenient for making estimates from a few trees. But with many trees, faster and more precise estimates can be obtained using the following equation:[14]

$$SI = 0.2198H^{1.1644}(1\text{-}e^{-0.0110A})^{-2.0364H^{-0.1775}}$$

where SI = site index (feet at 50 years),
H = total height of dominants and codominants (feet),
A = total age (years), and
e = base of natural logarithms.

Total age is needed to use the site index curves or equation, but breast height age is usually determined because balsam fir often has butt rot. To obtain total age, compare breast height age and total height values with the site index curves and estimate the general site class. Then use the following tabulation (Carmean and Hahn 1981) and add the number of years given for this site class to breast height age:

Site index	20	30	40	50	60	70
Years	15	13	11	10	9	8

[14] *Adapted from Carmean and Hahn (1981).*

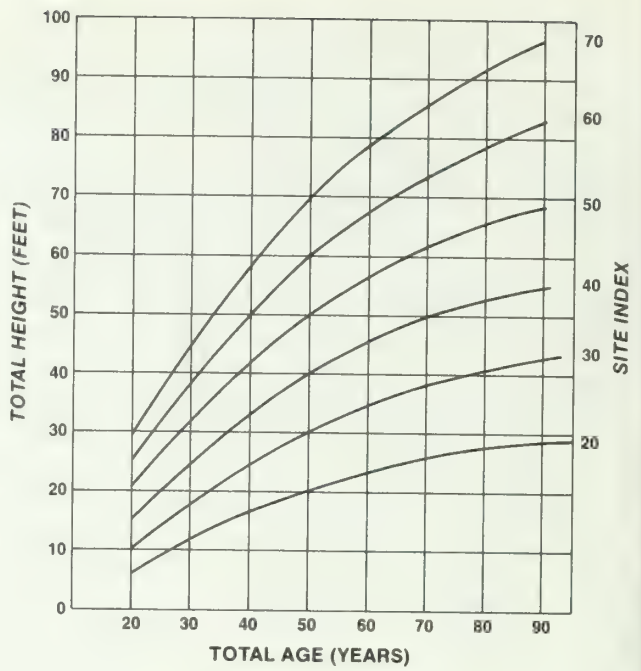


Figure 7.—*Site index curves for balsam fir stands in the Lake States. Adapted from Carmean and Hahn (1981).*

The foregoing procedure is good for obtaining consistent total ages, but it is important to remember that the years added are based on assumptions whose accuracy is unknown. Large errors can occur in estimating both total age and site index if the site trees initially grew faster or slower in height than assumed.

Unfortunately, many dominant and codominant firs are not suitable for site index measurement because they became established under other trees and have suffered from early suppression. This is particularly true in uneven-aged stands of balsam fir, but it applies also to even-aged fir stands that originated under associated species such as quaking aspen. In either case, if dominant and codominant trees of quaking aspen, paper birch, black spruce, or northern white-cedar are present and have not been suppressed, their site index values can be measured and then used to estimate balsam fir site index. The tabulation of comparative site indexes on page 5 is convenient for roughly estimating site index from a few trees. But if many trees are measured, the following equations (Carmean 1982) can be used to make faster, more precise estimates:

Species used to estimate balsam fir site index (SI_{BF})	Equation
Quaking aspen (QA)	$SI_{BF} = -1.366 + 0.851(SI_{QA})$
Paper birch (PB)	$SI_{BF} = 12.096 + 0.707(SI_{PB})$
Black spruce (BS)	$SI_{BF} = -7.212 + 1.168(SI_{BS})$
Northern white-cedar (NWC)	$SI_{BF} = -15.196 + 1.852(SI_{NWC})$

These equations should be applicable to most sites because they are based on a wide range of site indexes. The manager should use the equations cautiously, however, because they are derived from other equations that are based on few plots and/or have large standard errors.

Sometimes no suitable trees are available for estimating balsam fir site index. For example, overstory trees of fir or associates may be uneven-aged, indicating early suppression; the stand may have been clearcut recently; or it may be too young (generally less than 20 years old) for reliable site index measurements. In such instances general site classes for balsam fir can be determined from soil characteristics and stand composition as discussed under page 5.

TWIGS

The North Central Forest Experiment Station developed The Woodsman's Ideal Growth projection System (TWIGS) as a microcomputer version of the Station's Stand and Tree Evaluation and Modeling System (STEMS). Unlike STEMS, which can evaluate many stands at a time, TWIGS is a microcomputer program designed to intensively examine one stand at a time. The program simulates the growth, mortality, and management of trees in stands, using biologically based, individual-tree models developed for the Lake States. TWIGS can be used to estimate the present yield of any balsam fir stand and to project its growth and development as a result of various management (cutting) options, including no cutting. The program can also be used to evaluate the aeconomics of these options.

TWIGS is written in the Pascal language for use on microcomputers such as the APPLE II and IBM Personal Computer. It is also available in FORTRAN for use on the Data General computer system. However, the program is continually being modified and refined, so anyone desiring to use TWIGS should obtain the latest appropriate version from the North Central Forest Experiment Station, 1992 Folwell Avenue, St. Paul, Minnesota 55108. For a detailed description and sample run of TWIGS, consult Belcher (1982).

To obtain accurate results (output) from TWIGS, you must enter information (input) into the program that validly represents the stand being examined. The input needed includes: year and age of stand when measured, site index for balsam fir, and a "tree list." This list may consist of individual tree data from one sample plot or aggregated data from more than one plot. Either variable- or fixed-radius plots can be used. The data needed to prepare a tree list include: species, d.b.h., crown ratio (optional), expansion factor (number of trees per acre represented by each tree list entry), and tree class (acceptable, undesirable, or cull). If detailed tree data are not available, TREEGEN—a program separate from TWIGS but on the same diskette—can generate a hypothetical tree list from less detailed stand data.

An important feature of TWIGS is that it can "grow" a balsam fir stand following various simulated management (cutting) options; thus, you can see which one best fulfills the management objective. Output displayed or printed by the program includes stand summaries of: (1) initial conditions, showing present yield; (2) conditions after cutting, showing values for cut trees and the residual stand; and (3) conditions after projection, showing the effect of growth and mortality on future yield. These summaries include the number and basal area per acre of live, cut, and dead trees by species (or species group), plus a stand volume table showing board feet of sawtimber, cubic feet and cords of pulpwood, and tons and cords of fuelwood (residue). TWIGS also presents economic evaluations to further help you select a satisfactory management option.

Metric Conversion Factors

To convert	to	Multiply by
Acres	Hectares	0.405
Board feet[1]	Cubic meters	0.005
Board feet/acre[1]	Cubic meters/hectare	0.012
Chains	Meters	20.117
Cords[1]	Cubic meters	2.605
Cords/acre[1]	Cubic meters/hectare	6.437
Cubic feet	Cubic meters	0.028
Cubic feet/acre	Cubic meters/hectare	0.070
Degrees Fahrenheit	Degrees Celsius	([2])
Feet	Meters	0.305
Gallons	Liters	3.785
Gallons/acre	Liters/hectare	9.353
Inches	Centimeters	2.540
Number/acre	Number/hectare	2.471
Pounds	Kilograms	0.454
Pounds/acre	Kilograms/hectare	1.121
Square feet	Square meters	0.093
Square feet/acre	Square meters/hectare	0.230
Tons	Metric tons	0.907
Tons/acre	Metric tons/hectare	2.242

[1]*The conversion of board feet and cords to cubic meters can only be approximate; the factors are based on an assumed 5.663 board feet (log scale) per cubic foot and a cord with 92 cubic feet of solid material.*

[2]*To convert °F to °C, use the formula* $5/9(°F - 32)$ *or* $\frac{°F - 32}{1.8}$.

Common and Scientific Names of Plants and Animals

PLANTS
Alder, speckled ..... *Alnus rugosa*
Ash, black ..... *Fraxinus nigra*
Aspen, quaking ..... *Populus tremuloides*
Beech, American ..... *Fagus grandifolia*
Birch
  Paper ..... *Betula papyrifera*
  Yellow ..... *Betula alleghaniensis*
Fern, bracken ..... *Pteridium aquilinum*
Fir, balsam ..... *Abies balsamea*
Hazel, beaked ..... *Corylus cornuta*
Hemlock, eastern ..... *Tsuga canadensis*
Maple
  Red ..... *Acer rubrum*
  Sugar ..... *Acer saccharum*
Pine
  Eastern white ..... *Pinus strobus*
  Jack ..... *Pinus banksiana*
  Red ..... *Pinus resinosa*
Raspberry, red ..... *Rubus idaeus*
Rot, root (or butt)
  Brown cubical ..... Main fungi are:
    Balsam butt rot ..... *Tyromyces balsameus*
    [None] ..... *Coniophora puteana*
  White stringy ..... Main fungi are:
    Shoestring root rot ..... *Armillaria mellea*
    [None] ..... *Perenniporia subacida*
    [None] ..... *Resinicium bicolor*
    [None] ..... *Scytinostroma galactinum*
Rot, trunk ..... Main fungus is:
  Red heart rot .. *Haematostereum sanguinolentum*
Rust, white pine blister ..... *Cronartium ribicola*
Spruce
  Black ..... *Picea mariana*
  White ..... *Picea glauca*
Tamarack ..... *Larix laricina*
White-cedar, northern ..... *Thuja occidentalis*
Willow ..... *Salix* spp.

ANIMALS
Bear, black ..... *Ursus americanus*
Beaver ..... *Castor canadensis*
Beetle, balsam fir bark ..... *Pityokteines sparsus*
Bobcat ..... *Lynx rufus*
Budworm
  Eastern blackheaded ..... *Acleris variana*
  Spruce ..... *Choristoneura fumiferana*
Chalcid, balsam fir seed . *Megastigmus specularis*
Coneworm, fir ..... *Dioryctria abietivorella*
Deer, white-tailed ..... *Odocoileus virginianus*
Fisher ..... *Martes pennanti*
Grouse
  Ruffed ..... *Bonasa umbellus*
  Spruce ..... *Canachites canadensis*
Hare, snowshoe ..... *Lepus americanus*
Junco, dark-eyed ..... *Junco hyemalis*
Looper, hemlock ..... *Lambdina fiscellaria*
Lynx, Canada ..... *Lynx canadensis*
Marten, pine ..... *Martes americana*
Midge, balsam gall ..... *Paradiplosis tumifex*
Moose ..... *Alces alces*
Mouse, deer ..... *Peromyscus maniculatus*
Sawyer, balsam fir .... *Monochamus marmorator*
Squirrel, red ..... *Tamiasciurus hudsonicus*
Vole, red-backed ..... *Clethrionomys gapperi*
Warbler
  Blackburnian ..... *Dendroica fusca*
  Blackpoll ..... *Dendroica striata*
  Black-throated green ..... *Dendroica virens*
  Cape May ..... *Dendroica tigrina*
Wolf, timber ..... *Canis lupus*
Woodpecker
  Black-backed three-toed ..... *Picoides arcticus*
  Northern three-toed ..... *Picoides tridactylus*
Wren, winter ..... *Troglodytes troglodytes*

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.



☆ U.S. Government Printing Office: 1987—755-904/40144

Johnston, William F.
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Presents the resource manager with a key to the recommended practices for managing balsam fir stands, especially for timber. Discusses control of growth, establishment, composition, and damaging agents; also discusses managing for boughs and Christmas trees, wildlife habitat, esthetics, and water. Includes information on estimating yield and growth.

KEY WORDS: *Abies balsamea*, Lake States, timber management, silviculture, spruce budworm control, wildlife management.

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-112**

Michigan's Forest Statistics, 1987: An Inventory Update

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FOREWORD

Forest Inventory and Analysis (FIA) is a continuing endeavor as mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974, which was preceded by the McSweeney-McNary Forest Research Act of 1928. The objective of FIA is to periodically inventory the Nation's forest land to determine its extent, condition, and volume of timber, growth, and depletions. Up-to-date resource information is essential for framing intelligent forest policies and programs. USDA Forest Service regional experiment stations are responsible for conducting these inventories and publishing summary reports for individual States. The North Central Forest Experiment Station is responsible for Forest Inventory and Analysis work in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin.

CONTENTS

	Page
UPDATE HIGHLIGHTS	1
Timberland	1
Timber Volume	1
Net Growth	1
Removals	1
Biomass	1
BACKGROUND	1
METHODOLOGY	2
Land Change	2
Growth and Mortality	3
Regeneration	3
Removals	3
LITERATURE CITED	3
APPENDIX	4
PRINCIPAL TREE SPECIES GROUPS IN MICHIGAN	4
METRIC EQUIVALENTS OF UNITS USED IN THIS REPORT	5
DEFINITIONS	5
TABLES	9

MICHIGAN'S FOREST STATISTICS, 1987: AN INVENTORY UPDATE

W. Brad Smith, *Mensurationist*
and
Jerold T. Hahn, *Principal Mensurationist*

UPDATE HIGHLIGHTS

Timberland

- Timberland area declined from 17.5 million acres in 1980 to 17.3 million acres in 1987, a loss of less than 1 percent.
- The area of maple-birch forest type climbed 1.4 percent to 6.2 million acres as Michigan's second-growth forests continue to mature.
- Red pine is still the most popular plantation species, as shown by the 15,000-acre gain in the red pine forest type since 1980.

Timber Volume

- Growing-stock volume in 1987 is 20.6 billion cubic feet, 10 percent higher than the 18.7 billion cubic feet reported in 1980.
- Average growing-stock volume per acre in 1987 is 1,185 cubic feet, compared with 1,068 cubic feet in 1980.
- Sawtimber volume totaled 52.3 billion board feet in 1987, up 19 percent from 1980.

Net Growth

- Annual net growth increased from 39 cubic feet per acre per year in 1980 to 43 cubic feet in 1987.
- Mortality declined from 0.8 percent of inventory in 1980 to 0.6 percent in 1987. Much of the decline is attributed to increased management activity simulated in the update process.

Removals

- Growing-stock removals have risen sharply since 1979, climbing from 275 million cubic feet to 398 million cubic feet annually in 1986. Major industrial expansion in the Upper Peninsula and in the northern Lower Peninsula are primarily responsible for the increase.

Biomass

- Tree biomass totaled 1.2 billion green tons in 1987. Seventy-eight percent of this volume is in growing-stock trees, 8 percent is in cull trees, and 14 percent is in trees less than 5 inches d.b.h.
- The average green weight per cubic foot (including bark) for softwood species was 43 pounds; the average for hardwoods was 56 pounds.

BACKGROUND

Current facts about the Nation's forest resources such as area, timber volume, biomass, and prospective supply and demand are essential in forming sound management practices and policies. The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires the Forest Service to make and keep current a comprehensive inventory and analysis of renewable forest and rangeland resources.

The most recent field inventory data available for Michigan are dated 1980; however, tree growth models developed at the North Central Forest Experiment Station have made it possible for the Forest Inventory and Analysis (FIA) work unit to update inventory data to estimate the current resource. The purpose of this report is to present updated statistics for the State of Michigan that will be used for the 1990 RPA assessment. The tables provide data by forest survey unit (fig. 1) and represent the timberland base as of January 1, 1987. The term "update", as it is used here, is an estimate of current forest statistics derived by modeling the dynamic change



Figure 1.—*Forest Survey Units in Michigan, 1980.*

in a forest from a known time in the past. The major components of this change are land change, growth, mortality, regeneration, and removals.

METHODOLOGY

Land Change

The basic sample design used by FIA in the North Central Region is a two-phase sample consisting of a photo sample to estimate forest-nonforest area and a ground phase, which is a subsample of the photo sample to provide information about the volume and condition of the forest.

New photo work for the entire region would be too costly and time consuming with current technology. However, we've found that for update periods of 10 years or less, area change at the State level can be estimated using trend analysis and information from local resource managers. The data then provide the first-phase area factors to be applied to the updated plots.

We assumed the timberland base for public and industry ownerships was stable during the update period. For all other ownerships a modest annual decline of 0.1 percent was assumed, which reflects the resource managers' view that the impacts of urbanization and agricultural expansion have not seriously eroded the timberland base of the region.

The objectives of the diverse group of owners that hold Michigan's forest land play a significant role in the stability of the timberland base. Knowledge of these objectives is essential to strategic forest planning. Public agencies are mandated by law to provide detailed information about management plans that outline the policies and programs designed to ensure a viable forest resource into the future.

The timberland area figures presented here represent the most recent data available at the time the update was processed. The reader is cautioned to contact the appropriate public agency to verify or update area figures for any analysis that may be sensitive to local changes in the timberland base, such as recently designated reserved or deferred forest land. Area and volume figures would have to be adjusted accordingly for any ownerships affected by significant changes in the timberland base.

Additional information is available about nonindustrial private owners and their objectives in the North Central Station report, "The Private Forest Landowners of Michigan" (Carpenter and Hansen 1985).

Growth and Mortality

We used the Stand and Tree Evaluation and Modeling System (STEMS) (Belcher 1981) to update 7,706 forest inventory plots from the 1980 field survey to the year 1987. STEMS is a distance-independent, individual tree growth model designed to simulate tree growth and mortality for a diverse range of forest conditions.

Growth and mortality functions were calibrated and validated with data from throughout the Lake States (Buchman 1983, Holdaway and Brand 1983, 1985). Test projections over a range of forest conditions produced reliable results when compared with remeasurement data from the Lake States. Adjustment factors derived from recent remeasurement data in the Lake States were used to fine tune the model and improve precision (Holdaway 1985).

Regeneration

Although STEMS regeneration routines for the Lake States had not been fully developed at the time of the update, the outcome was not significantly affected. Most trees that became established on harvested land or in seedling stands at the beginning of the update would not have grown to merchantable size by the end of that 6-year period.

Removals

Removals data were derived by trend analysis using periodic pulpwood (Blyth and Smith 1985), saw log (Blyth *et al.* 1981), and veneer (Blyth and Smith 1984) reports and base year data for all removals provided in the 1980 Michigan report (Raile and Smith 1983). Removals attributed to loss of timberland were made by adjusting plot expansion factors to arrive at a specified set of current area figures by forest type. Estimates of timber removals in the Lake States may be reviewed in more detail in a recent article, "Tracking Timber Demand in the Lake States" (Smith and Blyth 1986).

The Lake States version of STEMS was modified to simulate actual removals. Computerized management guides (Brand 1981) were used to select a subset of inventory plots that were eligible for silvicultural treatment during the update period. These guides were used in lieu of detailed information on Michigan management strategies. A special removals algorithm scanned each selected plot to determine if it would be cut. The volume from cut plots was accumulated until the estimated volume of growing-stock removals by species was reached. Volume estimates were produced using volume equations developed for the Lake States (Hahn 1984, Smith 1985).

All area and volume figures for the update were reviewed for reasonableness and consistency by personnel from the Michigan Department of Natural Resources, the National Forest System, industry resource managers, and other private individuals. A more detailed description of the methodology will be presented later in a publication on inventory updating procedures in the North Central Region.

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APPENDIX

PRINCIPAL TREE SPECIES GROUPS IN MICHIGAN[1]

Softwoods
- Eastern white pine ..... *Pinus strobus*
- Red pine ..... *Pinus resinosa*
- Jack pine ..... *Pinus banksiana*
- Black spruce ..... *Picea mariana*
- White spruce ..... *Picea glauca*
- Balsam fir ..... *Abies balsamea*
- Tamarack ..... *Larix laricina*
- Northern white-cedar ..... *Thuja occidentalis*
- Other softwoods
  - Eastern recedar ..... *Juniperus virginiana*
  - Scotch pine ..... *Pinus sylvestrus*

Hardwoods
- White oaks
  - White oak ..... *Quercus alba*
  - Swamp white oak ..... *Quercus bicolor*
  - Bur oak ..... *Quercus marocarpa*
  - Chinkapin oak ..... *Quercus muehlenbergii*
  - Chestnut oak ..... *Quercus prinus*
- Select red oak
  - Northern red oak oak ..... *Quercus rubra*
- Other red oaks
  - Scarlet oak ..... *Quercus coccinea*
  - Northern pin oak ..... *Quercus ellipsoidalis*
  - Pin oak ..... *Quercus palustris*
  - Black oak ..... *Quercus velutina*
- Hickories
  - Bitternut hickory ..... *Carya cordiformis*
  - Pignut hickory ..... *Carya glabra*
  - Shellbark hickory ..... *Carya laciniosa*
  - Shagbark hickory ..... *Carya ovata*
  - Mockernut hickory ..... *Carya tomentosa*
- Yellow birch ..... *Betula alleghaniensis*
- Hard maples
  - Sugar maple ..... *Acer saccharum*
  - Black maple ..... *Acer nigrum*
- Soft maples
  - Red maple ..... *Acer rubrum*
  - Silver maple ..... *Acer saccharinum*
- American beech ..... *Fagus grandifolia*
- Ashes
  - White ash ..... *Fraxinus americana*
  - Black ash ..... *Fraxinus nigra*
  - Green ash ..... *Fraxinus pennsylvanica*

Balsam poplar ..... *Populus balsamifera*
Eastern cottonwood ..... *Populus deltoides*
Aspens
Bigtooth aspen..... *Populus grandidentata*
Quaking aspen ..... *Populus tremuloides*
Basswood..... *Tilia americana*
Yellow-poplar..... *Liriodendron tulipifera*
Black walnut..... *Juglans nigra*
Black cherry..... *Prunus serotina*
Butternut ..... *Juglans cinerea*
Elms
American elm ..... *Ulmus americana*
Slippery elm..... *Ulmus rubra*
Rock elm..... *Ulmus thomasii*
Paper birch..... *Betula papyrifera*
Other hardwoods
Boxelder ..... *Acer negundo*
Sweet birch..... *Betula lenta*
River birch..... *Betula nigra*
Black willow ..... *Salix nigra*
Ohio buckeye..... *Aesculus glabra*
Flowering dogwood..... *Cornus florida*
Honeylocust ..... *Gleditsia triacanthos*
Osage orange..... *Maclura pomifera*
Black tupelo..... *Nyssa sylvatica* var. *sylvatica*
Sycamore..... *Platanus occidentalis*
Black locust ..... *Robinia pseudoacacia*
Sassafras..... *Sassafras albidum*
Red mulberry..... *Morus rubra*
American chestnut..... *Castanea dentata*

METRIC EQUIVALENTS OF UNITS USED IN THIS REPORT

1 acre = 4,046.86 square meters or 0.405 hectare.
1,000 acres = 405 hectares.
1 cubic foot = 0.0283 cubic meter.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter.

DEFINITIONS

Acceptable trees.—Growing-stock trees of commercial species that meet specified standards of size and quality.

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal area of all trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Biomass.—The total above-ground weight, excluding foliage, of all live trees reported in green tons. Biomass is made up of 5 components:

Growing-stock bole and stump.—Biomass of a growing-stock tree from ground level to a 4-inch top.

Growing-stock top and limbs.—Biomass of a growing-stock tree above a 4-inch top and all limbs below the 4-inch top.

Cull bole and stump.—Biomass of a cull tree from ground level to a 4-inch top.

Cull top and limbs.—Biomass of a cull tree above a 4-inch top and all limbs below the 4-inch top.

1- to 5-inch trees.—Above ground biomass of all live trees 1- to 5-inches in diameter at breast height.

Commercial species.—Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

County and municipal land.—Land owned by counties and local public agencies or municipalities, or land leased to these governmental units for 50 years or more.

Cropland.—Land under cultivation within the past 24 months; including cropland harvested, crop failures, cultivated summer fallow, idle cropland used only for pasture, orchards, and land in soil improvement crops, but excluding land cultivated in developing improved pasture.

Cull.—Portions of a tree that are unusable for industrial wood products because of rot, form, or other defect.

Diameter classes.—A classification of trees based on diameter outside bark, measured at breast height (4.5 feet above the ground). (Note: d.b.h. is the common abbreviation for diameter at breast height. Two-inch diameter classes are commonly used in Forest Survey, with the even inch the approximate midpoint for a class. For example, the 6-inch class includes trees 5.0 through 6.9 inches d.b.h.)

Farm.—Any place from which or more of agricultural products were produced and sold during the year.

Farmer-owned land.—Land owned by farm operators.

Forest industry land.—Land owned by companies or individuals operating primary wood-using plants.

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for

nonforest use. (Note: Stocking is measured by comparison of basal area and/or number of trees, by age or size and spacing with specified standards.) The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water or clearings in forest areas shall be classed as forest if less than 120 feet wide. Also see definitions for land area, timberland, nontimberland, reserved forest land, stocking, woodland, and water.

Forest industry land.—Land owned by companies or individuals operating primary wood-using plants. Excludes land owned by small sawmill firms sawing less than 100,000 board feet annually.

Forest trees.—Woody plants having a well-developed stem and usually more than 12 feet tall at maturity.

Forest type.—A classification of forest land based on the species forming a plurality of live tree stocking. Major forest types are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

Oak-hickory.—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, beech, yellow-poplar, elm, and maple.)

Elm-ash-soft maple.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

Maple-birch.—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, hemlock, and basswood.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Exotic.—Forests in which species not native to the State comprise a plurality of the stocking. (Mostly Scotch pine plantations.)

Gross area.—The entire area of land and water as determined by the Bureau of the Census.

Growing-stock trees.—Live trees of commercial species qualifying as acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem. Cubic feet can be converted to cords by dividing by 79 cubic feet per solid wood cord.

Hardwoods.—Dicotyledonous trees, usually broadleaved and deciduous.

Idle farmland.—Includes former cropland, orchards, improved pastures, and farm sites not tended within the past 2 years and presently less than 16.7 percent stocked with trees.

Improved pasture.—Land currently improved for grazing by cultivating, seeding, irrigating, or clearing of trees or brush and less than 16.7 percent stocked with live trees.

Indian land.—All lands held in trust by the United States for individual Indians or tribes, or all lands, titles to which are held by individual Indians or tribes, subject to Federal restrictions against alienation.

Industrial wood.—All roundwood products, except fuelwood.

Land area.—*Bureau of the Census*.—The area of dry land and land temporarily or partly covered by water such as marshes, swamps, and river flood plains (omitting tidal flats below mean high tide); streams, sloughs, estuaries, and canals less than one-eighth of a statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

Forest Inventory and Analysis.—The same as the Bureau of the Census, except minimum width of streams, etc., is 120 feet and minimum size of lakes, etc., is 1 acre.

Live trees.—Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

Marsh.—Nonforest land that characteristically supports low, generally herbaceous or shrubby vegetation and that is intermittently covered with water.

Merchantable.—Refers to a pulpwood or saw log section that meets pulpwood or saw log specifications, respectively.

Miscellaneous federal land.—Federal land other than National Forest.

Miscellaneous private land.—Privately owned land other than forest-industry and farmer-owned land.

Mortality.—The volume of sound wood in growing-stock and sawtimber trees that die annually.

National Forest land.—Federal land that has been legally designated as National Forest or purchase units, and other land administered by the USDA Forest Service.

Net annual growth of growing-stock.—The annual change in volume of sound wood in live sawtimber and poletimber trees and the total volume of trees entering these classes through ingrowth, less volume losses resulting from natural causes.

Net annual growth of sawtimber.—The annual change in the volume of live sawtimber trees and the total volume of trees reaching sawtimber size, less volume losses resulting from natural causes.

Net volume.—Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

Nontimberland.—(a) Woodland and (b) reserved forest land.

Noncommercial species.—Tree species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial wood products.

Nonforest land.—Land that has never supported forests, and land formerly forested where use for timber management is precluded by development for other uses. (Note: Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide and more than 1 acre in area to qualify as nonforest land.)

a. *Nonforest land without trees*.—Nonforest land with no live trees present.

b. *Nonforest land with trees*.—Nonforest land with one or more trees per acre at least 5 inches d.b.h.

Nonstocked land.—Timberland less than 16.7 percent stocked with growing-stock trees.

Other removals.—Growing-stock trees removed but not utilized for products, or trees left standing but "removed" from the timberland classification by land use change. Examples are removals from cultural operations such as timber stand improvement work, land clearing, and changes in land use.

Ownership.—Property owned by one owner, regardless of the number of parcels in a specified area.

Pasture and range.—Land which is currently improved for grazing by cultivation seeding or irrigation plus land on which the natural plant cover is composed principally of native grasses, forbs, or shrubs valuable for forage.

Physiographic class.—A measure of soil and water conditions that affect tree growth on a site. The physiographic classes are:

Xeric sites.—Very dry soils where excessive drainage seriously limits both growth and species occurrence. Example: sandy jack pine plains.

Xeromesic sites.—Moderately dry soils where excessive drainage limits growth and species occurrence to some extent. Example: dry oak ridge.

Mesic sites.—Deep, well-drained soils. Growth and species occurrence are limited only by climate.

Hydromesic sites.—Moderately wet soils where insufficient drainage or infrequent flooding limits growth and species occurrence to some extent. Example: better drained bottomland hardwood sites.

Hydric sites.—Very wet sites where excess water seriously limits both growth and species occurrence. Example: frequently flooded river bottoms and spruce bogs.

Poletimber stands.—(See stand-size class.)

Poletimber trees.—Growing-stock trees of commercial species at least 5 inches d.b.h. but smaller than sawtimber size.

Reserved forest land.—Forest land sufficiently productive to qualify as timberland but withdrawn from timber utilization through statute, ad-

ministrative regulation, designation, or exclusive use for Christmas tree production, as indicated by annual shearing.

Rotten trees.—Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of extra cull volume in a tree is rotten.

Rough trees.—(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Salvable dead trees.—Standing or down dead trees that are considered merchantable by regional standards.

Saplings.—Live trees 1 to 5 inches d.b.h.

Sapling-seedling stands.—(See stand-size class.)

Saw log.—A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) for softwoods of 7 inches (9 inches for hardwoods) or other combinations of size and defect specified by regional standards.

Saw log portion.—That part of the bole of sawtimber trees between the stump and the saw log top.

Saw log top.—The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw log top is 7 inches d.o.b. for softwoods and 9 inches d.o.b. for hardwoods.

Sawtimber stands.—(See stand-size class.)

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting regional specifications for freedom from defect. Softwoods must be at least 9 inches d.b.h. Hardwoods must be at least 11 inches d.b.h.

Sawtimber volume.—Net volume of the saw log portion of live sawtimber in board feet, International 1/4-inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Seedlings.—Live trees less than 1 inch d.b.h. that are expected to survive. Only softwood seedlings more than 6 inches tall and hardwood seedlings more than 1 foot tall are counted.

Short-log (rough tree).—Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

Site class.—A classification of forest land in terms of inherent capacity to grow crops of industrial wood based on fully stocked natural stands.

Site index.—An expression of forest site quality based on the total height of free-growing dominant or codominant trees of a representative species in the forest type at age 50.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-area class.—The extent of a continuous forested area of the same forest type, stand-size class, and stand-density class.

Stand-size class.—A classification of forest land based on the size class of all live trees; that is, sawtimber, poletimber of seedlings and saplings. Only those types contributing to no more than 16 percent stocking at a point will be used to determine stand size class. Remember that stands with less than 16.7 percent stocking in growing stock trees will be classified as nonstocked. Noncommercial trees are not used for determining stand size classes.

Sawtimber stands.—Stands with at least the all live stocking in sawtimber and poletimber trees and with the sawtimber stocking equal to or larger than the poletimber stocking.

Poletimber stands.—Stands with at least half of the all live stocking in sawtimber and poletimber trees and with the poletimber stocking larger than the sawtimber stocking.

Sapling-seedling stands.—Stands with more than half of the all live stocking in saplings and/or seedlings.

State land.—Land owned by States, or land leased to these governmental units for 50 years or more.

Stocking.—The degree of occupancy of land by trees, measured by basal area and/or the number of trees in a stand by size or age and spacing, compared to the basal area and/or number of trees required to fully utilize the growth potential of the land; that is, the stocking standard. A stocking percent of 100 indicates full utilization of the site and is equivalent to 80 square feet of basal area per acre in trees 5 inches d.b.h. and larger. In a stand of trees less than 5 inches d.b.h., a stocking percent of 100 would indicate that the present number of trees is sufficient to produce 80 square feet of basal area per acre when the trees reach 5 inches d.b.h. Stands are grouped into the following stocking classes:

Overstocked stands.—Stands in which stocking of trees is 134.0 percent or more.

Fully stocked stands.—Stands in which stocking of trees is from 101.0 to 133.9 percent.

Medium stocked stands.—Stands in which stocking of trees is from 61.0 to 100.9 percent.

Poorly stocked stands.—Stands in which stocking of trees is from 16.7 to 60.9 percent.

Nonstocked areas.—Timberland on which stocking of trees is less than 16.7 percent.

Timber removals from growing stock.—The volume of sound wood in live sawtimber and poletimber trees removed annually for forest products (including roundwood products and logging residues) and for other removals. Roundwood products are logs, bolts, or other round sections cut from trees. Logging residues are the unused portions of cut trees plus unused trees killed by logging. Other removals are growing-stock trees removed by cultural operations such as timber stand improvement work, and by land clearing and changes in land use.

Timber removals from sawtimber.—The net board-foot volume of live sawtimber trees removed for forest products annually (including roundwood products and logging residues) and for other removals.

Timberland.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as timberland are capable of producing more than 20 cubic feet per acre per year of annual growth under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for producing of industrial wood in the foreseeable future.) Also see definition of pastured timberland.

Tree biomass.—The total aboveground weight (including the bark) of all live trees.

Tree size class.—A classification of trees based on diameter at breast height, including sawtimber trees, poletimber trees, saplings, and seedlings.

Upper stem portion.—That part of the bole of sawtimber trees above the saw log top to a minimum top diameter of 4 inches outside bark or to the point where the central stem breaks into limbs.

Urban and other areas.—Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches; powerlines; and other rights-of-way; or other nonforest land not included in any other specified land use class.

Water.—*Bureau of the Census*.—Permanent inland water surfaces, such as lakes, reservoirs, and ponds having 40 acres or more of area; streams, sloughs, estuaries, and canals one-eighth of a statute mile or more in width.

Noncensus.—Permanent inland water surfaces, such as lakes, reservoirs, and ponds having 1-39.9 acres of area; streams, sloughs, estuaries, and canals 120 feet to one-eighth of a statute mile in width.

Windbreak.—A group of trees less than 120 feet wide used for the protection of soil, cropfields, and buildings in use.

Wooded pasture.—Improved pasture with more than 16.7 percent stocking in live trees but less than 25 percent stocking in growing-stock trees. Area is currently improved for grazing or there is other evidence of grazing.

Wooded strip.—An acre or more of natural continuous forest land that would otherwise meet survey standards for timberland except that it is less than 120 feet wide.

Woodland.—Forest land incapable of producing 20 cubic feet per acre of annual growth or of yielding crops of industrial wood under natural conditions because of adverse site conditions. (Note: Adverse conditions include shallow soils, dry climate, poor drainage, high elevation, steepness, and rockiness.)

TABLES

Table 1.—Area of land by land use class and Forest Survey Unit, 1980 and 1987

Table 2.—Area of timberland by ownership class and Forest Survey Unit

Table 3.—Area of timberland by forest type, stand-age class, and Forest Survey Unit

Table 4.—Area of timberland by forest type, site-index class, and Forest Survey Unit

Table 5.—Area of timberland by forest type, stand-size class, and Forest Survey Unit

Table 6.—Net volume of growing stock on timberland, by forest type, stand-age class, and Forest Survey Unit

Table 7.—Net volume of sawtimber on timberland, by forest type, stand-age class, and Forest Survey Unit

Table 8.—Growing-stock volume and periodic growth on timberland by forest type, component of growth, and Forest Survey Unit

Table 9.—Growing-stock volume and periodic growth on timberland by species group, component of growth, and Forest Survey Unit

Table 10.—Sawtimber volume and periodic growth on timberland by forest type and component of growth
Table 11.—Sawtimber volume and periodic growth on timberland by species group and component of growth
Table 12.—Net volume of growing stock on timberland by species group and forest type
Table 13.—Net volume of sawtimber on timberland by species group and forest type
Table 14.—Net volume of growing stock on timberland by species group and diameter class
Table 15.—Net volume of sawtimber on timberland by species group and diameter class
Table 16.—Annual net growth mortality and removals of growing stock and sawtimber on timberland by softwoods and hardwoods
Table 17.—Net volume of short-log trees on timberland by species group and diameter class
Table 18.—Net volume of short-log trees on timberland by species group and diameter class
Table 19.—All live tree biomass on timberland by species group and tree biomass component

Table 1.--Area of land by land class, Michigan, 1980 and 1987

(In thousand acres)

Land class	All units		Forest survey unit							
			Eastern upper peninsula		Western upper peninsula		Northern lower peninsula		Southern lower peninsula	
	1980	1987	1980	1987	1980	1987	1980	1987	1980	1987
FOREST LAND										
Timberland										
Jack pine	837.6	832.9	230.2	223.3	88.7	82.2	506.4	515.1	12.3	12 3
Red pine	653.6	668.1	139.9	143.0	57.6	63.7	428.2	433.5	27.9	27.9
White pine	214.1	218.9	68.7	73.8	48.5	45 2	75.3	78 3	21 6	21 6
Balsam fir	634.2	607.4	216.9	207.0	366.0	357.4	51.3	43.0	-	
White spruce	99.9	99.9	29.9	29.9	40.6	40.6	21.9	21.9	7.5	7 5
Black spruce	519.8	512.7	282.9	279.3	209.0	205.5	27.9	27.9		
Northern white-cedar	1,172.3	1,185.4	595.1	599.0	210.1	210.1	354 1	362 2	13 0	14 1
Tamarack	114.9	109.0	43.8	40.7	36.0	34.1	30.7	29.8	4 4	4 4
Oak-hickory	1,779.3	1,731.3	19.1	19.1	22.4	17.6	1,064.1	1,043.7	673.7	650 9
Elm-ash-soft maple	1,327.3	1,268.2	191.0	177.1	168.3	158.8	416.4	402.4	551 6	529 9
Maple-birch	6,075.0	6,162.5	1,150.4	1,156.7	2,349.4	2,405.1	1,668.5	1,675.3	906.7	925.4
Aspen	3,408.1	3,325.4	669.4	669.4	730.9	696.9	1,823.0	1,795.7	184 8	163.4
Paper birch	374.1	366.6	110.1	110.1	142.9	142.9	114.5	107.0	6.6	6 6
Exotic	85.7	85.7	1.2	1.2	1.6	1.6	56 7	56.7	26.2	26 2
Nonstocked	171.9	167.6	40.1	40.1	28.6	26.7	63.0	60.6	40.2	40.2
Subtotal	17,467.8	17,341.6	3,788.7	3,769.7	4,500.6	4,488.4	6,702.0	6,653.1	2,476.5	2,430.4
Woodland	257.2	257.2	102.4	102.4	62.2	62.2	87.7	87.7	4.9	4 9
Reserved	622.1	622.1	127.6	127.6	266.7	266.7	147.0	147.0	80.8	80 8
Total	18,347.1	18,220.9	4,018.7	3,999.7	4,829.5	4,817.3	6,936.7	6,887.8	2,562.2	2,516.1
NONFOREST LAND										
Cropland	11,636.1	11,636.1	449.8	449.8	192.7	192.7	2,430.8	2,430.8	8,741.8	8,741.8
Pasture and range	1,265.0	1,265.0	3.9	3.9	141.2	141.2	685.5	685.5	434.4	434.4
Other	4,654.2	4,780.4	526.6	545.6	381.3	375.2	1,297.7	1,346.6	2,748.4	2,794.5
Total	17,555.3	17,681.5	980.3	999.3	696.9	709.1	4,414.0	4,462.9	11,924.6	11,970.7
TOTAL LAND	36,362.9	36,362.9	4,999.0	4,999.0	5,526.4	5,526.4	11,350.7	11,350.7	14,486.8	14,486.8
WATER (BUREAU OF THE CENSUS)	895.3	895.3	165.8	165.8	167.0	167.0	362.6	362.6	199.9	199 9
TOTAL LAND AND WATER	37,258.2	37,258.2	5,164.8	5,164.8	5,693.4	5,693.4	11,713.3	11,713.3	14,686.7	14,686.7

Table 2.--Area of timberland by ownership class and Forest Survey Unit, Michigan, 1987

(In thousand acres)

Ownership class	All units	Forest survey unit			
		Eastern upper peninsula	Western upper peninsula	Northern lower peninsula	Southern lower peninsula
National forest	2,453.4	743.3	831.4	863 8	14 9
Miscellaneous fed.	45.0	20.6	1.6	15.2	7.6
State	3,581.1	979.3	618.8	1,833.0	150.0
County and municipal	186.8	8.9	87.3	37.9	52.7
Indian	22.2	6.0	16.2	-	-
Forest industry	1,965.7	631.5	1,258.0	76.2	-
Farmer	3,054.6	467.8	190.6	1,263.9	1,132.3
Misc. private-corp.	1,486.0	223.5	660.2	463.8	138.5
Misc. private-indiv.	4,546.8	688.8	824.3	2,099.3	934.4
All owners	17,341.6	3,769.7	4,488.4	6,653.1	2,430.4

Table 3.--Area of timberland by forest type and stand-age class, Michigan, 1987

(In thousand acres)

Forest type	All ages	Stand-age class(years)									
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
All units											
Jack pine	832.9	152.8	103.4	73.7	157.6	193.0	99.6	22.2	25.8	2.3	2.5
Red pine	668.1	80.9	140.1	186.6	114.4	62.9	7.2	20.5	29.8	24.2	1.5
White pine	218.9	12.4	16.6	17.5	5.0	18.5	17.9	35.1	46.0	33.3	16.6
Balsam fir	607.4	69.5	70.1	51.1	95.4	87.6	88.8	58.0	61.4	22.5	3.0
White spruce	99.9	8.5	18.5	3.8	18.8	12.7	9.9	5.3	10.7	9.5	2.2
Black spruce	512.7	68.1	68.7	126.0	71.8	49.4	50.9	31.8	20.1	15.9	10.0
Northern white-cedar	1,185.4	27.2	55.3	90.2	74.4	63.0	115.1	142.6	267.2	224.9	125.5
Tamarack	109.0	19.6	13.8	15.6	10.9	5.6	16.6	10.5	6.5	7.9	2.0
Oak-hickory	1,731.3	502.9	117.8	29.8	106.7	174.3	286.1	240.3	241.4	30.4	1.6
Elm-ash-soft maple	1,268.2	216.6	150.3	93.7	114.1	115.9	144.7	93.1	168.4	131.4	40.0
Maple-birch	6,162.5	559.2	399.4	222.6	361.8	912.3	902.8	509.5	888.7	1,047.6	358.6
Aspen	3,325.4	1,107.7	544.0	143.4	343.2	478.9	406.5	157.4	108.8	30.8	4.7
Paper birch	366.6	32.4	29.5	10.6	25.6	40.1	94.2	80.4	32.4	14.9	6.5
Exotic	85.7	15.6	27.8	23.8	9.3	7.0	2.2	-	-	-	-
Nonstocked	167.6	112.1	25.1	8.3	8.0	5.4	5.1	-	3.6	-	-
All types	17,341.6	2,985.5	1,780.4	1,096.7	1,517.0	2,226.6	2,247.6	1,406.7	1,910.8	1,595.6	574.7
Eastern upper peninsula											
Jack pine	223.3	48.1	10.7	14.5	47.5	74.9	18.8	5.9	2.9	-	-
Red pine	143.0	27.1	31.4	23.0	34.5	8.5	1.4	3.0	9.1	5.0	-
White pine	73.8	9.6	5.3	3.2	3.3	4.4	8.7	11.0	11.1	9.6	7.6
Balsam fir	207.0	23.3	27.0	12.3	61.0	28.2	28.2	14.0	5.2	6.3	1.5
White spruce	29.9	3.0	6.4	1.2	1.5	5.9	3.1	1.6	5.7	1.5	-
Black spruce	279.3	35.4	34.1	87.9	53.8	22.7	20.3	14.2	7.8	3.1	-
Northern white-cedar	599.0	13.6	37.7	60.0	56.3	37.7	51.3	64.1	112.0	105.8	60.5
Tamarack	40.7	2.5	5.2	6.2	4.3	1.1	7.1	6.5	4.8	3.0	-
Oak-hickory	19.1	1.6	1.6	-	0.4	3.4	6.0	3.1	3.0	-	-
Elm-ash-soft maple	177.1	31.8	17.0	15.1	9.5	19.3	24.8	10.7	22.5	22.1	4.3
Maple-birch	1,156.7	70.8	60.8	42.6	73.0	177.7	144.2	107.0	161.6	226.2	92.8
Aspen	669.4	212.6	68.6	28.2	108.9	101.7	91.5	41.4	12.6	3.9	-
Paper birch	110.1	15.9	7.7	3.2	4.8	16.1	23.3	26.9	6.1	6.1	-
Exotic	1.2	-	-	1.2	-	-	-	-	-	-	-
Nonstocked	40.1	25.7	3.1	-	5.1	1.5	3.3	-	1.4	-	-
All types	3,769.7	521.0	316.6	298.6	463.9	503.1	432.0	309.4	365.8	392.6	166.7
Western upper peninsula											
Jack pine	82.2	15.5	4.2	7.2	12.2	22.7	20.4	-	-	-	-
Red pine	63.7	-	23.0	8.1	10.8	-	1.7	5.9	4.5	8.2	1.5
White pine	45.2	-	-	1.3	1.7	1.6	-	14.0	14.8	7.7	4.1
Balsam fir	357.4	38.8	32.1	36.6	34.4	55.8	55.6	35.9	50.5	16.2	1.5
White spruce	40.6	3.3	1.6	-	12.4	6.8	4.8	3.7	-	8.0	-
Black spruce	205.5	25.8	28.8	38.1	18.0	19.9	27.1	15.7	9.3	12.8	10.0
Northern white-cedar	210.1	4.7	7.6	9.8	2.8	11.7	17.9	26.0	48.8	51.4	29.4
Tamarack	34.1	4.9	6.4	5.2	1.2	4.5	5.6	1.6	-	2.7	2.0
Oak-hickory	17.6	-	-	1.1	1.2	3.4	-	2.3	3.7	4.3	1.6
Elm-ash-soft maple	158.8	23.8	16.4	7.5	9.1	10.2	12.7	13.0	27.0	22.5	16.6
Maple-birch	2,405.1	83.5	82.3	51.2	127.5	376.4	380.9	155.4	360.0	561.6	226.3
Aspen	696.9	192.5	79.0	25.9	76.8	151.1	99.0	24.0	45.5	3.1	-
Paper birch	142.9	5.0	10.8	5.0	8.0	14.6	42.8	25.9	17.8	6.5	6.5
Exotic	1.6	1.6	-	-	-	-	-	-	-	-	-
Nonstocked	26.7	19.9	5.5	-	1.3	-	-	-	-	-	-
All types	4,488.4	419.3	297.7	197.0	317.4	678.7	668.5	323.4	581.9	705.0	299.5

(Table 3 continued on next page)

(Table 3 continued)

Forest type	All ages	Stand-age class (years)									
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Northern lower peninsula											
Jack pine	515.1	84.4	88.5	52.0	94.6	95.4	56.2	16.3	22.9	2.3	2.5
Red pine	433.5	49.0	85.7	143.9	65.8	46.2	4.1	11.6	16.2	11.0	-
White pine	78.3	2.8	11.3	5.2	-	7.1	9.2	1.7	20.1	16.0	4.9
Balsam fir	43.0	7.4	11.0	2.2	-	3.6	5.0	8.1	5.7	-	-
White spruce	21.9	2.2	10.5	-	-	-	2.0	-	5.0	-	2.2
Black spruce	27.9	6.9	5.8	-	-	6.8	3.5	1.9	3.0	-	-
Northern white-cedar	362.2	5.8	10.0	13.2	15.3	13.6	45.9	52.5	102.8	67.5	35.6
Tamarack	29.8	7.8	2.2	4.2	5.4	-	3.9	2.4	1.7	2.2	-
Oak-hickory	1,043.7	259.2	73.2	11.6	48.7	100.9	228.7	175.7	138.8	6.9	-
Elm-ash-soft maple	402.4	67.4	49.1	19.7	30.2	51.2	36.7	46.2	59.8	31.2	10.9
Maple-birch	1,675.3	169.3	126.6	48.0	105.0	290.9	332.3	168.3	249.4	165.3	20.2
Aspen	1,795.7	641.5	367.5	77.8	129.7	211.5	201.4	87.1	50.7	23.8	4.7
Paper birch	107.0	11.5	7.7	2.4	9.5	9.4	28.1	27.6	8.5	2.3	-
Exotic	56.7	6.0	20.4	20.0	5.9	2.2	2.2	-	-	-	-
Nonstocked	60.6	36.1	8.7	6.3	1.6	3.9	1.8	-	2.2	-	-
All types	6,653.1	1,357.3	878.2	406.5	511.7	842.7	961.0	599.4	686.8	328.5	81.0
Southern lower peninsula											
Jack pine	12.3	4.8	-	-	3.3	-	4.2	-	-	-	-
Red pine	27.9	4.8	-	11.6	3.3	8.2	-	-	-	-	-
White pine	21.6	-	-	7.8	-	5.4	-	8.4	-	-	-
Balsam fir	-	-	-	-	-	-	-	-	-	-	-
White spruce	7.5	-	-	2.6	4.9	-	-	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	14.1	3.1	-	7.2	-	-	-	-	3.6	0.2	-
Tamarack	4.4	4.4	-	-	-	-	-	-	-	-	-
Oak-hickory	650.9	242.1	43.0	17.1	56.4	66.6	51.4	59.2	95.9	19.2	-
Elm-ash-soft maple	529.9	93.6	67.8	51.4	65.3	35.2	70.5	23.2	59.1	55.6	8.2
Maple-birch	925.4	235.6	129.7	80.8	56.3	67.3	45.4	78.8	117.7	94 5	19.3
Aspen	163.4	61.1	28.9	11.5	27.8	14.6	14.6	4.9	-	-	-
Paper birch	6.6	-	3.3	-	3.3	-	-	-	-	-	-
Exotic	26.2	8.0	7.4	2.6	3.4	4.8	-	-	-		-
Nonstocked	40.2	30.4	7.8	2.0	-	-	-	-	-	-	-
All types	2,430.4	687.9	287.9	194.6	224.0	202.1	186.1	174.5	276.3	169.5	27.5

Table 4.--Area of timberland by forest type and site-index class, Michigan, 1987

(In thousand acres)

Forest type	All classes	Site-index class (feet)								
		11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
All units										
Jack pine	832.9	-	11.8	122.6	258.5	269.5	124.4	27.4	18.7	
Red pine	668.1	-	-	2.6	153.3	217.0	162.5	94.0	38.7	-
White pine	218.9	-	-	18.1	44.8	89.8	37.4	19.7	9.1	
Balsam fir	607.4	2.8	9.2	59.6	169.1	256.4	85.9	9.6	11.8	3.0
White spruce	99.9	-	4.7	13.6	19.1	25.8	14.3	19.7	2.7	
Black spruce	512.7	-	49.6	223.4	175.4	48.8	13.6	1.9	-	
Northern white-cedar	1,185.4	75.0	538.8	370.2	131.1	29.6	33.6	7.1	-	
Tamarack	109.0	-	16.7	38.4	26.0	17.2	8.5		2.2	
Oak-hickory	1,731.3	-	2.3	64.6	303.7	455.0	444.5	294.8	127.0	39.4
Elm-ash-soft maple	1,268.2	-	9.9	123.2	153.2	249.8	317.3	184.0	115.9	114.9
Maple-birch	6,162.5	-	21.7	123.6	567.5	1,324.1	1,944.9	1,423.6	574.4	182.7
Aspen	3,325.4	-	2.6	55.0	211.0	580.0	948.0	933.3	493.5	102.0
Paper birch	366.6	-	1.4	18.7	37.3	144.3	122.6	36.4	5.9	
Exotic	85.7	-	-	4.2	22.4	20.5	28.0	9.5	-	1.1
Nonstocked	167.6	1.7	4.5	16.4	59.2	52.4	14.1	15.1	4.2	-
All types	17,341.6	79.5	673.2	1,254.2	2,331.6	3,780.2	4,299.6	3,076.1	1,404.1	443.1
Eastern upper peninsula										
Jack pine	223.3	-	11.8	58.6	48.7	74.7	23.4	5.2	0.9	
Red pine	143.0	-	-	-	34.5	59.5	47.3	1.7		
White pine	73.8	-	-	11.1	24.4	27.7	5.9	3.0	1.7	-
Balsam fir	207.0	1.5	2.8	14.0	64.2	93.3	26.8	3.0	-	1.4
White spruce	29.9	-	-	6.0	7.1	2.8	11.0	3.0		
Black spruce	279.3	-	13.0	126.3	113.5	20.6	4.4	1.5	-	
Northern white-cedar	599.0	43.3	305.5	162.7	60.5	14.2	8.1	4.7	-	
Tamarack	40.7	-	4.2	18.0	12.5	4.4	1.6	-		
Oak-hickory	19.1	-	-	1.5	0.4	4.6	6.5	6.1		
Elm-ash-soft maple	177.1	-	1.5	24.0	50.0	53.3	36.2	9.5	2.6	
Maple-birch	1,156.7	-	12.3	32.1	136.6	317.5	427.3	186.5	37.9	6.5
Aspen	669.4	-	-	25.9	77.1	157.3	203.8	160.2	40.1	5.0
Paper birch	110.1	-	-	6.3	13.7	47.5	36.5	4.6	1.5	-
Exotic	1.2	-	-	-	-	-	1.2	-	-	
Nonstocked	40.1	1.7	0.7	3.3	13.6	14.1	3.5	3.2	-	-
All types	3,769.7	46.5	351.8	489.8	656.8	891.5	843.5	392.2	84.7	12.9
Western upper peninsula										
Jack pine	82.2	-	-	1.7	5.0	9.1	41.7	14.4	10.3	-
Red pine	63.7	-	-	-	24.3	13.6	6.8	19.0	-	
White pine	45.2	-	-	-	7.7	27.9	8.4	1.2	-	-
Balsam fir	357.4	1.3	6.4	43.3	90.4	142.0	55.8	4.8	11.8	1.6
White spruce	40.6	-	-	3.3	9.8	13.0	3.3	11.2	-	-
Black spruce	205.5	-	34.7	87.2	54.3	24.5	4.4	0.4	-	
Northern white-cedar	210.1	16.2	103.7	58.4	18.3	2.6	10.9	-		
Tamarack	34.1	-	-	12.0	13.5	4.8	3.8		-	
Oak-hickory	17.6	-	-	1.7	2.2	3.3	9.3	1.1	-	
Elm-ash-soft maple	158.8	-	3.0	37.7	38.5	33.1	31.7	13.4	1.4	
Maple-birch	2,405.1	-	9.4	54.2	270.0	617.7	837.7	472.4	130.6	13.1
Aspen	696.9	-	-	4.9	29.9	121.3	206.9	221.2	95.8	16.9
Paper birch	142.9	-	1.3	3.1	6.7	61.5	54.4	15.9	-	-
Exotic	1.6	-	-	-	-	1.6	-	-		
Nonstocked	26.7	-	2.3	2.4	2.6	16.0	2.5	0.9	-	-
All types	4,488.4	17.5	160.8	309.9	573.2	1,092.0	1,277.6	775.9	249.9	31.6

(Table 4 continued on next page)

(Table 4 continued)

Forest type	All classes	Site-index class (feet)								
		11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
Northern lower peninsula										
Jack pine	515.1	-	-	62.3	204.8	185.7	47.0	7.8	7.5	-
Red pine	433.5	-	-	2.6	94.5	141.6	108.4	66.7	19.7	-
White pine	78.3	-	-	7.0	12.7	23.1	23.1	7.1	5.3	-
Balsam fir	43.0	-	-	2.3	14.5	21.1	3.3	1.8	-	-
White spruce	21.9	-	4.7	4.3	2.2	2.5	-	5.5	2.7	-
Black spruce	27.9	-	1.9	9.9	7.6	3.7	4.8	-	-	-
Northern white-cedar	362.2	15.5	122.4	145.5	52.3	12.6	11.5	2.4	-	-
Tamarack	29.8	-	8.1	8.4	-	8.0	3.1	-	2.2	-
Oak-hickory	1,043.7	-	2.3	48.8	260.6	333.8	240.9	116.9	28.7	11.7
Elm-ash-soft maple	402.4	-	5.4	38.3	45.7	95.0	116.1	66.6	13.3	22.0
Maple-birch	1,675.3	-	-	27.8	117.8	300.3	469.1	480.5	212.0	67.8
Aspen	1,795.7	-	2.6	24.2	104.0	271.3	501.3	526.7	289.1	76.5
Paper birch	107.0	-	0.1	9.3	16.9	32.0	31.7	12.6	4.4	-
Exotic	56.7	-	-	-	12.4	12.9	20.8	9.5	-	1.1
Nonstocked	60.6	-	1.5	10.7	22.7	12.2	6.3	7.2	-	-
All types	6,653.1	15.5	149.0	401.4	968.7	1,455.8	1,587.4	1,311.3	584.9	179.1
Southern lower peninsula										
Jack pine	12.3	-	-	-	-	-	12.3	-	-	-
Red pine	27.9	-	-	-	-	2.3	-	6.6	19.0	-
White pine	21.6	-	-	-	-	11.1	-	8.4	2.1	-
Balsam fir	-	-	-	-	-	-	-	-	-	-
White spruce	7.5	-	-	-	-	7.5	-	-	-	-
Black spruce	-	-	-	-	-	-	-	-	-	-
Northern white-cedar	14.1	-	7.2	3.6	-	0.2	3.1	-	-	-
Tamarack	4.4	-	4.4	-	-	-	-	-	-	-
Oak-hickory	650.9	-	-	12.6	40.5	113.3	187.8	170.7	98.3	27.7
Elm-ash-soft maple	529.9	-	-	23.2	19.0	68.4	133.3	94.5	98.6	92.9
Maple-birch	925.4	-	-	9.5	43.1	88.6	210.8	284.2	193.9	95.3
Aspen	163.4	-	-	-	-	30.1	36.0	25.2	68.5	3.6
Paper birch	6.6	-	-	-	-	3.3	-	3.3	-	-
Exotic	26.2	-	-	4.2	10.0	6.0	6.0	-	-	-
Nonstocked	40.2	-	-	-	20.3	10.1	1.8	3.8	4.2	-
All types	2,430.4	-	11.6	53.1	132.9	340.9	591.1	596.7	484.6	219.5

Table 5 --Area of timberland by forest type and stand-size class, Michigan, 1987

(In thousand acres)

Forest type	All classes	Stand size class			
		Sawtimber	Poletimber	Sapling & seedling	Nonstocked
All units					
Jack pine	832.9	109.8	421.8	301.3	-
Red pine	668.1	124.8	328.9	214.4	-
White pine	218.9	143.4	39.9	35.6	-
Balsam fir	607.4	119.2	299.2	189.0	-
White spruce	99.9	27.0	44.7	28.2	-
Black spruce	512.7	7.5	250.3	254.9	-
Northern white-cedar	1,185.4	308.2	646.5	230.7	-
Tamarack	109.0	11.7	33.8	63.5	-
Oak-hickory	1,731.3	348.3	755.0	628.0	-
Elm-ash-soft maple	1,268.2	409.1	448.8	410.3	-
Maple birch	6,162.5	2,501.9	2,594.7	1,065.9	-
Aspen	3,325.4	291.9	1,305.0	1,728.5	-
Paper birch	366.6	34.9	257.7	74.0	-
Exotic	85.7	4.8	34.7	46.2	-
Nonstocked	167.6	-	-	-	167.6
All types	17,341.6	4,442.5	7,461.0	5,270.5	167.6
Eastern upper peninsula					
Jack pine	223.3	23.1	142.1	58.1	-
Red pine	143.0	29.1	59.9	54.0	-
White pine	73.8	42.0	15.2	16.6	-
Balsam fir	207.0	45.9	97.0	64.1	-
White spruce	29.9	8.9	10.4	10.6	-
Black spruce	279.3	3.1	143.8	132.4	-
Northern white-cedar	599.0	132.4	307.6	159.0	-
Tamarack	40.7	1.4	18.3	21.0	-
Oak-hickory	19.1	4.6	11.3	3.2	-
Elm-ash-soft maple	177.1	44.8	65.3	67.0	-
Maple-birch	1,156.7	516.2	483.2	157.3	-
Aspen	669.4	56.7	318.5	294.2	-
Paper birch	110.1	9.5	72.3	28.3	-
Exotic	1.2	-	1.2	-	-
Nonstocked	40.1	-	-	-	40.1
All types	3,769.7	917.7	1,746.1	1,065.8	40.1
Western upper peninsula					
Jack pine	82.2	24.1	37.5	20.6	-
Red pine	63.7	21.8	22.6	19.3	-
White pine	45.2	38.9	6.3	-	-
Balsam fir	357.4	65.9	187.2	104.3	-
White spruce	40.6	13.4	22.3	4.9	-
Black spruce	205.5	4.4	93.2	107.9	-
Northern white-cedar	210.1	88.0	97.2	24.9	-
Tamarack	34.1	4.0	9.4	20.7	-
Oak-hickory	17.6	9.6	6.9	1.1	-
Elm-ash-soft maple	158.8	48.8	63.9	46.1	-
Maple-birch	2,405.1	1,156.5	1,045.5	203.1	-
Aspen	696.9	54.6	353.9	288.4	-
Paper birch	142.9	20.9	101.2	20.8	-
Exotic	1.6	-	-	1.6	-
Nonstocked	26.7	-	-	-	26.7
All types	4,488.4	1,550.9	2,047.1	863.7	26.7

(Table 5 continued on next page)

(Table 5 continued) Northern lower peninsula

Forest type	All classes	Stand size class: Sawtimber	Poletimber	Sapling & seedling	Nonstocked
	Northern lower peninsula				
Jack pine	515.1	58.4	238.9	217.8	-
Red pine	433.5	64.0	228.4	141.1	-
White pine	78.3	52.0	12.2	14.1	
Balsam fir	43.0	7.4	15.0	20.6	
White spruce	21.9	4.7	4.5	12.7	-
Black spruce	27.9	-	13.3	14.6	
Northern white-cedar	362.2	87.8	237.9	36.5	
Tamarack	29.8	6.3	6.1	17.4	-
Oak-hickory	1,043.7	135.8	564.6	343.3	-
Elm-ash-soft maple	402.4	115.5	146.5	140.4	-
Maple-birch	1,675.3	474.6	870.4	330.3	-
Aspen	1,795.7	169.6	565.9	1,060.2	-
Paper birch	107.0	4.5	80.9	21.6	-
Exotic	56.7	-	25.3	31.4	-
Nonstocked	60.6	-	-	-	60.6
All types	6,653.1	1,180.6	3,009.9	2,402.0	60.6
	Southern lower peninsula				
Jack pine	12.3	4.2	3.3	4.8	-
Red pine	27.9	9.9	18.0	-	-
White pine	21.6	10.5	6.2	4.9	-
Balsam fir	-	-	-	-	-
White spruce	7.5	-	7.5	-	-
Black spruce	-	-	-	-	-
Northern white-cedar	14.1	-	3.8	10.3	-
Tamarack	4.4	-	-	4.4	-
Oak-hickory	650.9	198.3	172.2	280.4	-
Elm-ash-soft maple	529.9	200.0	173.1	156.8	-
Maple-birch	925.4	354.6	195.6	375.2	-
Aspen	163.4	11.0	66.7	85.7	-
Paper birch	6.6	-	3.3	3.3	-
Exotic	26.2	4.8	8.2	13.2	-
Nonstocked	40.2	-	-	-	40.2
All types	2,430.4	793.3	657.9	939.0	40.2

Table 6.--Net volume of growing stock on timberland by forest type and stand-age class, Michigan, 1987

(In million cubic feet)

Forest type	All ages	Stand-age class(years) 1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
All units											
Jack pine	667.4	38.9	46.0	51.9	147.3	224.3	116.9	19.5	19.5	1.9	1.2
Red pine	1,124.5	44.8	135.4	421.8	245.5	110.0	8.9	46.9	53.3	55.7	2.2
White pine	363.1	6.8	12.0	19.9	4.0	31.1	24.2	92.9	77.4	67.3	27.5
Balsam fir	721.9	36.0	38.7	34.7	135.3	141.2	122.8	88.9	90.9	31.6	1.8
White spruce	141.0	4.1	15.4	4.0	32.5	17.8	16.8	14.1	20.1	13.6	2.6
Black spruce	358.1	27.3	28.4	58.3	63.9	45.8	47.3	30.0	23.3	20.6	13.2
Northern white-cedar	1,548.5	10.6	31.6	55.1	57.1	78.2	166.8	219.5	409.8	367.3	152.5
Tamarack	59.4	5.4	7.7	7.0	4.2	3.9	12.7	7.4	4.6	6.5	-
Oak-hickory	1,682.0	167.8	48.7	34.0	129.1	240.5	373.4	309.1	340.1	37.9	1.4
Elm-ash-soft maple	1,296.3	82.5	84.9	81.5	139.1	133.3	180.9	136.7	241.8	174.1	41.5
Maple-birch	8,887.1	270.8	253.0	267.5	534.7	1,530.3	1,479.0	839.1	1,485.5	1,698.3	528.9
Aspen	3,162.8	467.7	310.1	132.0	477.1	725.4	657.7	208.9	141.0	37.4	5.5
Paper birch	469.6	17.5	16.2	6.8	36.7	59.6	156.6	108.1	43.0	19.3	5.8
Exotic	69.5	2.9	11.2	23.9	16.9	12.8	1.8	-	-	-	-
Nonstocked	6.4	2.1	1.0	0.3	0.5	1.0	0.9	-	0.6	-	-
All types	20,557.6	1,185.2	1,040.3	1,198.7	2,023.9	3,355.2	3,366.7	2,121.1	2,950.9	2,531.5	784.1
Eastern upper peninsula											
Jack pine	161.2	6.9	3.5	8.4	43.9	70.7	21.2	4.1	2.5	-	-
Red pine	185.7	11.2	30.3	45.7	57.7	10.4	1.5	5.0	12.1	11.8	-
White pine	92.4	4.6	3.1	3.7	1.7	5.5	8.4	20.9	17.2	15.8	11.5
Balsam fir	232.8	12.9	14.6	7.5	87.1	42.7	38.1	17.2	6.9	4.8	1.0
White spruce	43.8	0.6	3.8	1.0	2.3	10.0	6.0	5.6	12.8	1.7	-
Black spruce	184.7	13.9	16.5	40.0	50.3	21.7	18.4	11.3	9.8	2.8	-
Northern white-cedar	732.5	4.1	20.0	36.8	45.2	43.7	73.9	100.1	170.8	164.8	73.1
Tamarack	24.4	0.4	2.3	2.9	1.0	1.0	5.0	4.9	4.2	2.7	-
Oak-hickory	15.6	-	2.2	-	-	2.4	6.9	1.8	2.3	-	-
Elm-ash-soft maple	174.1	10.6	11.9	10.1	8.8	20.9	36.5	14.9	25.8	30.9	3.7
Maple-birch	1,612.8	37.3	48.0	44.8	98.4	276.9	214.1	178.0	251.1	330.9	133.3
Aspen	633.4	86.9	33.8	15.5	148.7	151.4	128.7	48.1	14.5	5.8	-
Paper birch	133.2	10.7	4.4	1.2	5.0	20.4	40.1	35.9	7.3	8.2	-
Exotic	2.4	-	-	2.4	-	-	-	-	-	-	-
Nonstocked	2.6	0.9	0.2	-	0.3	0.4	0.6	-	0.2	-	-
All types	4,231.6	201.0	194.6	220.0	550.4	678.1	599.4	447.8	537.5	580.2	222.6
Western upper peninsula											
Jack pine	89.6	2.6	2.4	13.3	11.7	32.7	26.9	-	-	-	-
Red pine	118.1	-	18.4	23.6	25.0	-	2.4	15.8	11.1	19.6	2.2
White pine	101.4	-	-	2.3	2.3	2.0	-	40.1	27.6	19.7	7.4
Balsam fir	450.3	19.5	17.3	26.1	48.2	94.6	79.2	58.3	79.5	26.8	0.8
White spruce	66.3	2.1	1.1	-	25.6	7.8	9.3	8.5	-	11.9	-
Black spruce	157.5	12.4	10.0	18.3	13.6	16.7	27.2	18.2	10.1	17.8	13.2
Northern white-cedar	282.6	1.3	4.8	5.9	2.3	14.3	28.4	35.9	73.0	75.8	40.9
Tamarack	16.3	1.8	2.4	1.6	0.4	2.9	4.3	0.3	-	2.6	-
Oak-hickory	24.4	-	-	1.6	2.6	5.7	-	4.5	5.4	3.2	1.4
Elm-ash-soft maple	164.4	7.7	12.9	5.5	9.9	9.9	16.7	14.6	40.3	29.1	17.8
Maple-birch	3,783.5	49.9	59.5	59.8	207.4	644.2	630.2	250.5	605.9	951.3	324.8
Aspen	755.8	76.6	47.2	38.4	124.7	215.7	149.7	35.9	64.1	3.5	
Paper birch	188.8	2.8	7.0	3.9	12.7	24.0	66.4	33.5	25.2	7.5	5.8
Exotic	-	-	-	-	-	-	-	-	-	-	-
Nonstocked	1.2	0.7	0.3	-	0.2	-	-	-	-	-	-
All types	6,200.2	177.4	183.3	200.3	486.6	1,070.5	1,040.7	516.1	942.2	1,168.8	414.3

(Table 6 continued on next page)

(Table 6 continued)

Forest type	All ages	Stand-age class(years) 1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Northern lower peninsula											
Jack pine	403.2	25.3	40.1	30.2	88.2	120.9	63.0	15.4	17.0	1.9	1.2
Red pine	763.5	28.3	86.7	327.9	154.9	80.2	5.0	26.1	30.1	24.3	
White pine	122.7	2.2	8.9	11.5	-	10.2	15.8	1.1	32.6	31.8	8.6
Balsam fir	38.8	3.6	6.8	1.1	-	3.9	5.5	13.4	4.5		
White spruce	23.3	1.4	10.5	-	-	-	1.5	-	7.3		2.6
Black spruce	15.9	1.0	1.9	-	-	7.4	1.7	0.5	3.4		
Northern white-cedar	528.3	5.0	6.8	9.5	9.6	20.2	64.5	83.5	164.0	126.7	38.5
Tamarack	16.5	1.0	3.0	2.5	2.8	-	3.4	2.2	0.4	1.2	
Oak-hickory	987.0	65.8	27.1	10.2	61.6	134.7	287.8	223.7	168.3	7.8	-
Elm-ash-soft maple	437.5	33.8	23.8	10.4	45.6	61.7	50.7	65.4	87.6	45.0	13.5
Maple-birch	2,478.5	74.4	81.8	53.3	155.6	506.3	554.7	296.5	447.2	274.1	34.6
Aspen	1,621.2	271.8	202.3	68.9	179.4	336.0	346.5	120.3	62.4	28.1	5.5
Paper birch	141.9	4.0	3.0	1.7	15.1	15.2	50.1	38.7	10.5	3.6	
Exotic	44.6	0.5	5.2	20.7	13.8	2.6	1.8	-			
Nonstocked	2.2	0.2	0.4	0.3	-	0.6	0.3	-	0.4	-	-
All types	7,625.1	518.3	508.3	548.2	726.6	1,299.9	1,452.3	886.8	1,035.7	544.5	104.5
Southern lower peninsula											
Jack pine	13.4	4.1	-	-	3.5	-	5.8	-	-		
Red pine	57.2	5.3	-	24.6	7.9	19.4	-	-	-		
White pine	46.6	-	-	2.4	-	13.4	-	30.8	-		
Balsam fir	-	-	-	-	-	-	-	-			
White spruce	7.6	-	-	3.0	4.6	-	-	-			
Black spruce	-	-	-	-	-	-	-	-	-	-	
Northern white-cedar	5.1	0.2	-	2.9	-	-	-		2.0		
Tamarack	2.2	2.2	-	-	-	-	-	-			
Oak-hickory	655.0	102.0	19.4	22.2	64.9	97.7	78.7	79.1	164.1	26.9	
Elm-ash-soft maple	520.3	30.4	36.3	55.5	74.8	40.8	77.0	41.8	88.1	69.1	6.5
Maple-birch	1,012.3	109.2	63.7	109.6	73.3	102.9	80.0	114.1	181.3	142.0	36.2
Aspen	152.4	32.4	26.8	9.2	24.3	22.3	32.8	4.6	-		
Paper birch	5.7	-	1.8	-	3.9	-	-	-	-	-	
Exotic	22.5	2.4	6.0	0.8	3.1	10.2	-	-	-		
Nonstocked	0.4	0.3	0.1	-	-	-	-	-	-		-
All types	2,500.7	288.5	154.1	230.2	260.3	306.7	274.3	270.4	435.5	238.0	42.7

Table 7.--Net volume of sawtimber on timberland by forest type and stand-age class, Michigan, 1987

(In million board feet) 1/

Forest type	All ages	Stand-age class (years)								
		1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
All units											
Jack pine	1,643.6	97.8	96.2	70.7	375.4	526.7	336.9	58.5	69.5	6.2	5.5
Red pine	2,479.2	44.7	110.7	561.4	688.7	356.8	35.4	190.2	235.8	248.7	6.9
White pine	1,467.8	11.8	47.4	35.2	13.4	91.0	91.1	402.2	337.7	305.9	132.2
Balsam fir	1,862.8	98.7	62.8	52.3	394.1	344.1	299.3	265.8	295.9	103.5	6.3
White spruce	386.2	14.5	32.3	3.4	63.7	58.3	36.2	50.9	63.5	52.8	10.1
Black spruce	615.6	45.7	46.4	112.1	79.5	75.6	64.8	46.5	27.4	77.4	40.2
Northern white-cedar	2,978.0	19.0	35.7	56.9	57.4	120.5	246.5	308.2	665.5	977.0	491.3
Tamarack	112.0	8.6	17.0	12.6	1.2	6.5	16.6	17.4	15.2	16.9	
Oak-hickory	4,514.7	563.1	127.8	74.9	260.9	525.5	782.2	833.8	1,174.9	165.3	6.3
Elm-ash-soft maple	3,452.1	167.1	137.4	163.2	272.6	245.1	491.1	387.2	818.0	622.6	147.8
Maple-birch	25,569.5	616.0	523.2	516.1	1,058.6	3,071.2	3,294.6	2,507.5	5,076.1	6,591.2	2,215.0
Aspen	6,288.0	985.5	465.5	194.9	805.6	1,410.1	1,408.7	484.0	391.1	123.5	19.1
Paper birch	781.2	29.5	25.1	3.2	49.9	93.4	226.5	166.7	100.5	64.6	21.8
Exotic	98.9	1.1	6.4	14.5	25.0	47.6	4.3				
Nonstocked	14.2	0.5	1.5	0.9	1.5	4.5	3.2		2.1		
All types	52,263.8	2,703.6	1,735.4	1,872.3	4,147.5	6,976.9	7,337.9	5,659.1	9,273.2	9,355.5	3,202.4
Eastern upper peninsula											
Jack pine	418.7	18.6	13.0	12.9	118.5	169.0	55.6	19.4	11.7		
Red pine	510.6	22.1	16.0	75.8	217.3	36.9	7.1	20.6	64.4	50.4	
White pine	382.4	7.3	13.3	8.8	7.3	19.1	29.7	104.6	69.7	70.6	52.0
Balsam fir	620.6	40.9	28.8	2.4	292.5	99.0	83.0	30.0	21.3	18.0	4.2
White spruce	139.3	2.9	11.3	1.9	9.0	29.4	15.6	22.8	38.5	7.9	
Black spruce	299.0	19.9	28.4	97.0	57.5	26.4	32.7	16.0	12.9	8.2	
Northern white-cedar	1,307.3	9.3	23.0	34.1	49.0	58.2	102.9	128.2	291.5	393.7	217.4
Tamarack	45.6	1.3	2.2	4.1	1.2	1.5	6.2	10.3	12.0	6.8	
Oak-hickory	49.1	-	1.4	-	0.1	6.4	22.7	10.7	7.8		
Elm-ash soft maple	427.6	19.4	16.0	13.1	11.2	38.7	83.0	31.1	93.3	107.7	14.1
Maple-birch	4,985.7	102.2	107.4	107.5	199.5	628.5	543.8	555.7	897.9	1,279.0	564.2
Aspen	1,179.8	173.5	45.0	26.2	222.3	289.5	250.5	109.5	45.2	18.1	
Paper birch	233.6	17.9	9.7	-	3.8	37.8	69.1	51.6	15.0	28.7	
Exotic	5.2	-	-	5.2			-		-		
Nonstocked	6.9	0.5	0.7	-	0.8	2.4	2.0		0.5		
All types	10,611.4	435.8	316.2	389.0	1,190.0	1,442.8	1,303.9	1,110.5	1,581.7	1,989.1	852.4
Western upper peninsula											
Jack pine	277.8	8.9	7.0	24.1	27.8	95.5	114.5				
Red pine	330.1	-	17.1	32.9	65.4	-	8.8	57.4	46.3	95.4	6.8
White pine	431.1	-	-	3.5	6.1	4.1	-	172.3	119.0	91.3	34.8
Balsam fir	1,153.1	44.6	24.8	46.7	101.6	238.6	206.7	141.5	261.5	85.5	1.6
White spruce	182.0	10.5	2.5	-	48.7	28.9	18.4	28.1		44.9	
Black spruce	288.2	23.9	12.2	15.1	22.0	34.5	31.0	30.5	9.6	69.2	40.2
Northern white-cedar	683.8	2.7	6.0	8.0	2.4	18.7	49.5	61.4	148.7	236.4	150.0
Tamarack	38.5	7.3	8.5	1.9	-	5.0	8.2	0.7		6.9	
Oak-hickory	77.7		-	2.3	5.2	15.4	-	8.3	22.0	18.2	6.3
Elm-ash-soft maple	439.1	21.4	21.6	11.4	22.3	18.2	40.9	30.6	103.6	100.8	68.3
Maple-birch	11,192.1	102.5	125.6	116.6	387.4	1,248.2	1,432.8	645.4	2,004.0	3,674.5	1,455.1
Aspen	1,600.8	179.1	88.8	37.0	201.8	457.4	332.4	94.2	200.4	9.7	
Paper birch	343.4	4.6	10.2	2.2	24.7	35.1	86.0	66.7	65.6	26.5	21.8
Exotic	-	-	-		-						
Nonstocked	1.5	-	0.8	-	0.7	-	-	-	-	-	
All types	17,039.2	405.5	325.1	301.7	916.1	2,199.6	2,329.2	1,337.1	2,980.7	4,459.3	1,784.9

(Table 7 continued on next page)

(Table 7 continued)

Forest type	All ages	Stand-age class (years) 1-20	21-30	31-40	41-50	51-60	61-70	71-80	81-100	101-120	121+
Northern lower peninsula											
Jack pine	917.4	61.8	76.2	33.7	227.7	262.2	147.0	39.3	57.8	6.2	5.5
Red pine	1,461.9	10.8	77.6	401.8	377.1	234.9	19.5	112.2	125.1	102.9	
White pine	483.0	4.5	34.1	13.7		25.8	61.4	5.2	149.0	143.9	45.4
Balsam fir	89.1	13.2	9.2	3.2	-	6.5	9.6	34.3	13.1	-	
White spruce	57.4	1.1	18.5			-	2.7	-	25.0		10.1
Black spruce	28.4	1.9	5.8			14.7	1.1		4.9	-	
Northern white cedar	977.9	7.0	6.7	13.6	6.0	43.6	94.1	118.6	218.4	346.0	123.9
Tamarack	27.9		6.3	6.6		-	2.2	6.4	3.2	3.2	-
Oak-hickory	2,284.0	202.7	63.4	13.3	112.3	264.6	530.8	539.5	521.4	36.0	-
Elm-ash-soft maple	1,126.9	67.5	37.3	16.9	90.1	108.8	131.8	172.8	289.4	166.6	45.7
Maple-birch	6,287.7	171.0	160.2	75.0	314.0	904.6	1,064.3	891.1	1,501.0	1,064.0	142.5
Aspen	3,214.5	569.6	315.8	117.0	344.7	626.0	718.1	263.0	145.5	95.7	19.1
Paper birch	193.6	7.0	-	1.0	16.0	20.5	71.4	48.4	19.9	9.4	
Exotic	44.5	-	4.4	9.3	22.1	4.4	4.3			-	
Nonstocked	5.8			0.9		2.1	1.2		1.6	-	-
All types	17,200.0	1,118.1	815.5	706.0	1,510.0	2,518.7	2,859.5	2,230.8	3,075.3	1,973.9	392.2
Southern lower peninsula											
Jack pine	29.7	8.5		-	1.4	-	19.8	-	-	-	-
Red pine	176.6	11.8	-	50.9	28.9	85.0				-	
White pine	171.3	-		9.2		42.0		120.1	-		
Balsam fir	-	-	-			-			-		-
White spruce	7.5	-	-	1.5	6.0	-			-	-	
Black spruce	-	-		-		-				-	
Northern white-cedar	9.0	-		1.2		-		-	6.9	0.9	
Tamarack				-	-			-		-	-
Oak-hickory	2,103.9	360.4	63.0	59.3	143.3	239.1	228.7	275.3	623.7	111.1	
Elm-ash-soft maple	1,458.5	58.8	62.5	121.8	149.0	79.4	235.4	152.7	331.7	247.5	19.7
Maple-birch	3,104.0	240.3	130.0	217.0	157.7	289.9	253.7	415.3	673.2	573.7	153.2
Aspen	292.9	63.3	15.9	14.7	36.8	37.2	107.7	17.3	-	-	
Paper birch	10.6	-	5.2	-	5.4			-	-	-	
Exotic	49.2	1.1	2.0	-	2.9	43.2		-		-	
Nonstocked	-	-		-			-		-		-
All types	7,413.2	744.2	278.6	475.6	531.4	815.8	845.3	980.7	1,635.5	933.2	172.9

1/ International 1/4-inch rule

Table 8.--Growing stock volume and periodic growth on timberland by forest type and component of growth, Michigan, 1980-1987

(In million cubic feet)

All units

Forest type	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Jack pine	620.6	117.6	35.9	30.5	-48.5	135.5	-80.6	-8.1	667.4
Red pine	743.0	225.4	156.0	46.4	-14.2	413.6	-32.1	-	1,124.5
White pine	304.0	68.3	8.7	10.2	-9.0	78.2	-13.0	-6.1	363.1
Balsam fir	657.2	127.9	35.6	20.3	-47.2	136.6	-49.9	-22.0	721.9
White spruce	110.7	37.4	5.4	6.7	-9.0	40.5	-10.2	-	141.0
Black spruce	342.1	39.4	19.3	7.4	-34.9	31.2	-14.0	1.2	358.1
Northern white-cedar	1,507.5	105.1	84.2	33.6	-104.4	118.5	-77.5		1,548.5
Tamarack	53.1	5.7	7.0	1.7	-3.9	10.5	-1.8	2.4	59.4
Oak-hickory	1,886.3	269.7	37.2	86.7	-75.1	318.5	-467.6	-55.2	1,682.0
Elm-ash-soft maple	1,248.9	186.6	61.4	28.9	-55.8	221.1	-134.7	-39.0	1,296.3
Maple-birch	7,624.5	1,540.0	266.2	269.8	-308.9	1,767.1	-504.5	-	8,887.1
Aspen	3,077.4	597.9	188.6	191.2	-217.8	759.9	-614.9	59.6	3,162.8
Paper birch	428.3	65.7	21.3	5.9	-19.2	73.7	-17.3	15.1	469.6
Exotic	47.0	13.6	7.8	1.5	-0.4	22.5	-	-	69.5
Nonstocked	3.6	1.5	1.1	0.3	-	2.9	-	-0.1	6.4
All types	18,654.2	3,401.8	935.7	741.1	-948.3	4,130.3	-2,018.1	-208.8	20,557.6
Eastern upper peninsula									
Jack pine	177.1	17.3	4.0	5.4	-11.8	14.9	-25.0	5.8	161.2
Red pine	126.7	32.0	31.3	7.1	-4.2	66.2	-7.2	-	185.7
White pine	79.1	14.7	3.9	2.5	-3.1	18.0	-4.7	-	92.4
Balsam fir	215.1	35.1	11.2	4.3	-12.7	37.9	-14.1	-6.1	232.8
White spruce	41.9	8.1	0.9	1.3	-3.1	7.2	-5.3		43.8
Black spruce	172.8	17.9	10.0	2.5	-13.1	17.3	-5.2	0.2	184.7
Northern white-cedar	743.0	21.2	47.1	9.7	-39.8	38.2	-48.7		732.5
Tamarack	24.3	0.8	1.5	0.6	-2.1	0.8	-	-0.7	24.4
Oak-hickory	16.6	1.0	0.8	1.2	-1.4	1.6	-2.6	-	15.6
Elm-ash-soft maple	189.6	12.6	8.1	2.8	-11.8	11.7	-24.1	-3.1	174.1
Maple-birch	1,469.9	242.2	42.2	40.5	-54.8	270.1	-127.2	-	1,612.8
Aspen	617.1	90.9	33.7	24.7	-48.6	100.7	-84.4	-	633.4
Paper birch	115.8	14.7	8.2	1.3	-3.8	20.4	-3.0	-	133.2
Exotic	1.6	0.4	0.4	-	-	0.8			2.4
Nonstocked	1.6	0.5	0.4	0.1	-	1.0	-	-	2.6
All types	3,992.2	509.4	203.7	104.0	-210.3	606.8	-351.5	-15.9	4,231.6
Western upper peninsula									
Jack pine	99.3	16.2	2.9	2.6	-9.5	12.2	-19.6	-2.3	89.6
Red pine	74.3	27.5	13.3	6.6	-2.0	45.4	-1.6	-	118.1
White pine	96.1	19.0	0.8	1.7	-3.1	18.4	-7.0	-6.1	101.4
Balsam fir	393.5	83.8	23.2	12.8	-29.8	90.0	-27.7	-5.5	450.3
White spruce	49.9	20.1	2.2	3.3	-4.9	20.7	-4.3	-	66.3
Black spruce	156.2	17.5	8.8	4.5	-19.7	11.1	-8.8	1.0	157.5
Northern white-cedar	293.3	11.1	8.8	1.9	-22.9	-1.1	-9.6	-	282.6
Tamarack	16.4	2.1	1.2	0.8	-1.2	2.9	-1.8	-1.2	16.3
Oak-hickory	29.6	1.2	1.1	1.0	-1.5	1.8	-6.5	0.5	24.4
Elm-ash-soft maple	187.9	15.0	7.8	5.9	-13.7	15.0	-35.6	-2.9	164.4
Maple-birch	3,190.5	747.4	101.6	107.3	-158.5	797.8	-204.8	-	3,783.5
Aspen	693.9	168.3	48.1	57.5	-56.5	217.4	-143.4	-12.1	755.8
Paper birch	179.3	19.9	7.3	2.3	-9.0	20.5	-11.0	-	188.8
Exotic	-	-	-	-	-	-	-	-	-
Nonstocked	0.5	0.1	0.5	0.1	-	0.7	-	-	1.2
All types	5,460.7	1,149.2	227.6	208.3	-332.3	1,252.8	-481.7	-31.6	6,200.2

(Table 8 continued on next page)

(Table 8 continued)

Forest type	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Northern lower peninsula									
Jack pine	332.9	83.0	27.9	22.3	-26.9	106.3	-36.0	-	403.2
Red pine	498.2	152.4	109.5	31.2	-8.0	285.1	-19.8	-	763.5
White pine	91.5	24.6	3.6	5.9	-1.6	32.5	-1.3	-	122.7
Balsam fir	48.6	9.0	1.2	3.2	-4.7	8.7	-8.1	-10.4	38.8
White spruce	14.6	6.5	1.7	2.1	-1.0	9.3	-0.6	-	23.3
Black spruce	13.1	4.0	0.5	0.4	-2.1	2.8	-	-	15.9
Northern white-cedar	467.7	72.7	27.5	21.0	-41.7	79.5	-18.9	-	528.3
Tamarack	11.5	2.5	3.4	0.2	-0.6	5.5	-	-0.5	16.5
Oak-hickory	1,018.9	175.0	27.4	44.7	-49.1	198.0	-200.8	-29.1	987.0
Elm-ash-soft maple	398.2	70.9	22.8	9.2	-16.4	86.5	-32.3	-14.9	437.5
Maple-birch	2,098.8	396.2	83.1	81.6	-69.2	491.7	-112.0	-	2,478.5
Aspen	1,633.8	307.9	95.4	102.9	-107.1	399.1	-378.8	-32.9	1,621.2
Paper birch	128.8	29.8	5.8	2.3	-6.4	31.5	-3.3	-15.1	141.9
Exotic	28.7	9.0	5.9	1.4	-0.4	15.9	-	-	44.6
Nonstocked	1.5	0.8	-	-	-	0.8	-	-0.1	2.2
All types	6,786.8	1,344.3	415.7	328.4	-335.2	1,753.2	-811.9	-103.0	7,625.1
Southern lower peninsula									
Jack pine	11.3	1.1	1.1	0.2	-0.3	2.1	-	-	13.4
Red pine	43.8	13.5	1.9	1.5	-	16.9	-3.5	-	57.2
White pine	37.3	10.0	0.4	0.1	-1.2	9.3	-	-	46.6
Balsam fir	-	-	-	-	-	-	-	-	-
White spruce	4.3	2.7	0.6	-	-	3.3	-	-	7.6
Black spruce	-	-	-	-	-	-	-	-	-
Northern white-cedar	3.5	0.1	0.8	1.0	-	1.9	-0.3	-	5.1
Tamarack	0.9	0.3	0.9	0.1	-	1.3	-	-	2.2
Oak-hickory	821.2	92.5	7.9	39.8	-23.1	117.1	-257.7	-25.6	655.0
Elm-ash-soft maple	473.2	88.1	22.7	11.0	-13.9	107.9	-42.7	-18.1	520.3
Maple-birch	865.3	154.2	39.3	40.4	-26.4	207.5	-60.5	-	1,012.3
Aspen	132.6	30.8	11.4	6.1	-5.6	42.7	-8.3	-14.6	152.4
Paper birch	4.4	1.3	-	-	-	1.3	-	-	5.7
Exotic	16.7	4.2	1.5	0.1	-	5.8	-	-	22.5
Nonstocked	-	0.1	0.2	0.1	-	0.4	-	-	0.4
All types	2,414.5	398.9	88.7	100.4	-70.5	517.5	373.0	-58.3	2,500.7

1/ Figures have been adjusted from those published after the 1980 survey to conform to changes in survey definitions and procedures.
2/ Includes growth on ingrowth, mortality and removals.

Table 9.--Growing stock volume and periodic growth on timberland by species group and component of growth, Michigan, 1980 1987

(In million cubic feet)

All units

Species group	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	637.7	123.6	32.8	33.0	-55.5	133.9	-93.0	-8 8	669.8
Red pine	784.2	235.6	186.6	62.5	-1.7	483.0	-66.5	-3 9	1,196 8
White pine	559.7	130.3	6.8	9.8	-5.7	141.2	-19.6	-10.2	671.1
White spruce	368.9	191.2	19.5	25.9	-13.6	223.0	17.5	5.1	569.3
Black spruce	354.1	27.5	14.7	8.6	-61.7	-10.9	-20.1	3 7	319.4
Balsam fir	789.2	155.2	58.9	27.0	-96.6	144.5	-48.9	13.8	871.0
Hemlock	509.2	83.8	2.7	11.8	-14.7	83.6	-36.0	1.2	555.6
Tamarack	104.8	7.5	8.5	3.6	-15.0	4.6	-4.3	1.8	103.3
Eastern redcedar	1.0	0.1	-	-	-	0.1		-	1.1
Northern white-cedar	1,415.5	104.5	72.6	15.4	-25.9	166.6	-36.4	-3 4	1,542.3
Other softwoods	50.0	21.5	9.4	6.4	-0.1	37.2	-	-	87.2
Total	5,574.3	1,080.8	412.5	204.0	-290.5	1,406.8	-342.3	-51.9	6,586.9
Hardwoods									
Select white oak	463.9	67.6	5.4	13.6	-1.1	85.5	-72.1	-11.2	466.1
Select red oak	1,132.9	178.3	12.0	37.3	-50.9	176.7	-180.8	-27.8	1,101.0
Other red oak	240.9	28.6	0.7	9.1	-19.7	18.7	-59.9	-3.9	195.8
Select hickory	61.2	7.9	2.4	1.6	-1.6	10.3	-4.2	-1.2	66.1
Other hickory	51.3	7.1	3.0	1.0	-2.0	9.1	-3.3	-1.0	56.1
Basswood	634.9	166.0	7.8	18.3	14.1	178.0	-31.9	-1.7	779.3
Beech	319.9	59.9	6.5	11.8	-6.3	71.9	-39.1	-0.6	352.1
Yellow birch	435.0	50.9	5.3	12.5	-52.6	16.1	-30.3	-1.0	419.8
Hard maple	2,483.7	493.4	113.4	107.7	-62.2	652.3	-236.8	-1.1	2,898.1
Soft maple	2,199.4	371.0	104.8	51.8	-72.7	454.9	-148.8	-24.5	2,481.0
Elm	232.3	52.0	4.0	18.6	-24.3	50.3	-60.2	-2.3	220.1
Black ash	256.8	24.6	30.8	7.6	-25.3	37.7	10.7	-4.7	279.1
White & green ash	432.0	86.5	28.6	13.8	10.0	118.9	35.7	-7.5	507.7
Sycamore	14.8	2.3	-	0.2	-0.8	1.7	1.4	-0.3	14.8
Cottonwood	67.5	14.1	-	1.9	-0.2	15.8	-11.2	-2.4	69.7
Willow	32.3	4.7	0.3	0.8	-1.0	4.8	-4.2	-0.8	32.1
Hackberry	0.8	0.1	-	0.1	-0.3	-0.1	-	-0.1	0.6
Balsam poplar	271.2	68.0	4.4	10.4	-30.9	51.9	-14.6	-4.9	303 6
Bigtooth aspen	925.8	209.4	25.7	81.0	-78.6	237.5	-266 6	-17.3	879.4
Quaking aspen	1,639.7	315.1	101.2	115.7	165.4	366.6	-368 6	-23.8	1,613.9
Paper birch	780.6	61.2	38.4	9.8	27.7	81.7	-50.8	-15.1	796.4
River birch	0.4	-	-	-	-	-	-	-	0.4
Black cherry	316.5	40.8	21.1	8.4	-6.5	63.8	-27.6	-2.7	350.0
Black walnut	27.0	1.7	0.9	0.5	-1.2	1.9	-2.3	0.8	25 8
Butternut	4.3	0.7	1.3	0.4	-	2.4	-0.5	-	6.2
Yellow poplar	16.6	2.0	-	0.4	-	2.4	-4.1	-0.1	14.8
Other hardwoods	38.2	7.1	5.2	2.8	-2.4	12.7	-10.1	-0.1	40.7
Total	13,079.9	2,321.0	523.2	537.1	-657.8	2,723.5	-1,675.8	-156.9	13,970.7
All species	18,654.2	3,401.8	935.7	741.1	-948.3	4,130.3	-2,018.1	-208.8	20,557.6

(Table 9 continued on next page)

(Table 9 continued)

Eastern upper peninsula

Species group	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	184.3	15.9	3.1	5.0	-12.9	11.1	27.1	-5.3	163.0
Red pine	127.0	32.0	32.8	9.9	-0.2	74.5	-16.4	-	185.1
White pine	152.0	33.0	0.8	3.9	-1.8	35.9	-11.5	1.2	175.2
White spruce	132.4	56.0	6.6	7.2	-4.2	65.6	8.9	-0.6	188.5
Black spruce	173.2	10.9	7.8	3.0	-26.9	-5.2	12.4	1.0	154.6
Balsam fir	270.8	41.0	24.2	9.6	-30.0	44.8	-24.4	4.9	286.3
Hemlock	141.2	17.1	0.7	3.6	-3.7	17.7	16.4	-0.5	142.0
Tamarack	40.8	0.9	2.4	1.4	-4.4	0.3	-1.9	-0.1	39.1
Eastern redcedar	-	-	-	-	-	-	-	-	-
Northern white-cedar	640.0	7.1	37.4	2.4	-10.3	36.6	-24.4	-0.3	651.9
Other softwoods	1.8	0.4	0.4	-	-	0.8	-	-	2.6
Total	1,863.5	214.3	116.2	46.0	-94.4	282.1	-143.4	-13.9	1,988.3
Hardwoods									
Select white oak	0.3	-	-	-	-				0.3
Select red oak	19.6	2.5	0.6	0.1	-0.6	2.6	-1.2	-	21.0
Other red oak	-	-	-	-	-	-			
Select hickory	-	-	-	-	-	-		-	
Other hickory	-	-	-	-	-	-	-		
Basswood	46.8	8.5	0.9	1.0	-0.6	9.8	-5.8		50.8
Beech	142.2	38.3	4.5	6.4	-2.4	46.8	21.1	-	167.9
Yellow birch	96.5	8.1	0.3	1.6	-10.7	-0.7	9.4	0.4	86.0
Hard maple	486.9	76.9	16.8	17.3	-10.7	100.3	-55.0	-	532.2
Soft maple	451.6	54.4	23.1	6.0	-17.1	66.4	-21.2	-0.3	496.5
Elm	33.0	6.1	0.2	1.8	-3.1	5.0	-9.2	0.5	28.3
Black ash	47.3	1.3	8.1	0.8	-5.6	4.6	-1.4		50.5
White & green ash	22.0	2.2	1.2	0.5	-0.4	3.5	-0.6		24.9
Sycamore	-	-	-	-		-	-		
Cottonwood	0.3	0.3	-	-	-	0.3		-	0.6
Willow	-	-	-	-	-	-	-	-	
Hackberry	-	-	-	-	-	-		-	
Balsam poplar	111.6	26.7	2.1	4.7	-13.6	19.9	-6.8	0.6	124.1
Bigtooth aspen	60.7	12.5	0.8	2.4	-4.1	11.6	-9.4		62.9
Quaking aspen	331.1	43.5	16.2	12.5	-37.8	34.4	-48.8	-0.1	316.6
Paper birch	232.3	9.8	11.8	2.7	-8.3	16.0	-17.5	-0.1	230.7
River birch	-	-	-	-	-	-	-		
Black cherry	46.3	4.0	0.9	0.2	-0.9	4.2	-0.6	-	49.9
Black walnut	-	-	-	-	-	-	-		-
Butternut	-	-	-	-	-	-	-	-	
Yellow poplar	-	-	-	-	-	-	-	-	
Other hardwoods	0.2	-	-	-	-	-	-0.1	-	0.1
Total	2,128.7	295.1	87.5	58.0	-115.9	324.7	-208.1	-2.0	2,243.3
All species	3,992.2	509.4	203.7	104.0	-210.3	606.8	-351.5	-15.9	4,231.6

(Table 9 continued on next page)

(Table 9 continued)

Western upper peninsula

Species group	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	106.5	15.6	3.6	2.5	-11.6	10.1	-20.1	-1.9	94.6
Red pine	73.8	27.9	16.4	11.2	-0.2	55.3	14.4	-1.9	112.8
White pine	169.2	37.0	0.5	1.9	1.4	38.0	-7.0	7.2	193.0
White spruce	198.7	115.5	11.0	15.5	-6.1	135.9	8.4	-3.6	322.6
Black spruce	144.9	12.4	5.5	4.7	-26.6	-4.0	7.4	-2.3	131.2
Balsam fir	414.2	88.7	29.3	13.9	-50.3	81.6	-18.2	4.8	472.8
Hemlock	297.0	53.4	0.8	7.1	-10.3	51.0	-19.1	-0.4	328.5
Tamarack	33.7	2.3	2.5	1.1	-3.7	2.2	-2.4	1.0	32.5
Eastern redcedar	0.1	-	-	-	-	-	-		0.1
Northern white-cedar	368.9	18.1	8.2	0.8	-8.6	18.5	-6.0	0.2	381.2
Other softwoods	0.3	0.2	-	-	-	0.2	-	-	0.5
Total	1,807.3	371.1	77.8	58.7	-118.8	388.8	-103.0	-23.3	2,069.8
Hardwoods									
Select white oak	0.8	0.1		-		0.1		-	0.9
Select red oak	76.0	14.6	0.8	2.0	-4.1	13.3	3.9	0.1	85.3
Other red oak	-	-	-	-	-	-			
Select hickory	-	-	-	-	-	-		-	
Other hickory	-	-	-	-	-	-			
Basswood	191.1	70.0	3.7	5.3	-5.1	73.9	9.1	0.1	255.8
Beech	0.4	0.1	-	0.1	-	0.2	-0.4		0.2
Yellow birch	299.2	37.6	3.9	9.8	-38.6	12.7	-20.4	0.5	291.0
Hard maple	1,244.0	276.4	59.0	44.9	-30.6	349.7	-97.2		1,496.5
Soft maple	589.2	113.5	27.1	8.6	-22.4	126.8	-21.4		694.6
Elm	124.6	24.3	1.0	9.0	-16.5	17.8	-32.0	0.7	109.7
Black ash	94.5	7.1	5.5	2.2	-10.1	4.7	-2.8		96.4
White & green ash	29.5	10.6	2.0	0.8	-1.3	12.1	1.3		40.3
Sycamore	-	-	-	-	-	-	-	-	
Cottonwood	0.2	0.1	-	-	-	0.1	-	-0.1	0.2
Willow	-	-	-	-	-	-			
Hackberry	-	-	-	-	-	-	-		
Balsam poplar	50.5	13.2	1.0	2.8	-4.6	12.4	4.5	-1.5	56.9
Bigtooth aspen	100.6	33.9	1.4	11.2	-8.7	37.8	-25.9	4.1	108.4
Quaking aspen	553.8	154.2	29.7	49.9	-61.7	172.1	-141.4	1.2	583.3
Paper birch	246.5	15.3	9.6	2.5	-8.6	18.8	-17.7		247.6
River birch	0.1	-	-	-	-				0.1
Black cherry	52.3	7.1	5.1	0.5	-1.2	11.5	-0.7		63.1
Black walnut	-		-	-	-				
Butternut	-	-	-	-	-	-			
Yellow poplar	-	-	-	-	-	-		-	
Other hardwoods	0.1	-	-	-	-	-	-		0.1
Total	3,653.4	778.1	149.8	149.6	-213.5	864.0	-378.7	-8.3	4,130.4
All species	5,460.7	1,149.2	227.6	208.3	-332.3	1,252.8	-481.7	-31.6	6,200.2

(Table 9 continued on next page)

(Table 9 continued)

Northern lower peninsula

Species group	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	333.7	90.5	26.1	25.5	-30.3	111.8	-45.5	-1.4	398.6
Red pine	532.3	158.8	136.0	39.7	-1.3	333.2	-31.1	-2.0	832.4
White pine	171.1	42.6	4.5	2.9	-1.3	48.7	-1.1	-1.2	217.5
White spruce	36.0	17.3	1.9	3.2	-3.3	19.1	-0.2	-0.9	54.0
Black spruce	36.0	4.2	1.4	0.9	-8.2	-1.7	-0.3	-0.4	33.6
Balsam fir	104.0	25.5	5.4	3.5	-16.3	18.1	-6.3	-4.1	111.7
Hemlock	63.9	12.0	1.2	1.1	-0.7	13.6	-0.5	-0.3	76.7
Tamarack	26.5	3.6	1.9	1.0	-6.3	0.2	-	-0.6	26.1
Eastern redcedar	0.4	-	-	-	-	-	-	-	0.4
Northern white-cedar	402.9	79.3	26.4	11.3	-7.0	110.0	-6.0	-2.9	504.0
Other softwoods	24.4	14.9	7.0	4.2	-0.1	26.0	-	-	50.4
Total	1,731.2	448.7	211.8	93.3	-74.8	679.0	-91.0	-13.8	2,305.4
Hardwoods									
Select white oak	187.6	39.7	3.8	6.1	-0.8	48.8	-21.6	-4.5	210.3
Select red oak	706.4	115.1	8.7	21.1	-37.2	107.7	-92.4	-17.2	704.5
Other red oak	135.6	17.9	0.7	5.8	-11.5	12.9	-29.8	-1.2	117.5
Select hickory	0.8	-	-	-	-	-	-	-	0.8
Other hickory	1.4	0.1	0.7	0.1	-	0.9	-0.2	-	2.1
Basswood	312.1	72.3	2.4	8.2	-6.8	76.1	-11.6	-1.0	375.6
Beech	128.1	16.7	2.0	2.4	-2.2	18.9	-8.0	-0.3	138.7
Yellow birch	32.3	4.1	0.8	1.1	-3.3	2.7	-0.5	-	34.5
Hard maple	641.7	121.8	32.6	38.7	-18.0	175.1	-74.7	-0.7	744.4
Soft maple	765.5	138.2	41.4	23.4	-20.1	182.9	-54.4	-14.9	879.1
Elm	25.5	6.2	0.3	3.1	-2.4	7.2	-8.7	-0.1	23.9
Black ash	86.0	11.6	11.7	3.9	-7.5	19.7	-4.9	-3.5	97.3
White & green ash	178.3	38.5	6.4	3.7	-4.6	44.0	-11.1	-3.6	207.6
Sycamore	0.8	0.2	-	-	-	0.2	-	-0.2	0.8
Cottonwood	9.8	2.6	-	0.2	-	2.8	-2.2	-0.2	10.2
Willow	6.3	1.1	-	0.1	-0.3	0.9	-	-	7.2
Hackberry	-	-	-	-	-	-	-	-	-
Balsam poplar	98.7	24.7	1.0	1.9	-10.8	16.8	-3.3	-1.7	110.5
Bigtooth aspen	685.0	142.9	22.3	63.1	-60.1	168.2	-216.7	-8.1	628.4
Quaking aspen	671.6	97.1	47.9	47.0	-61.8	130.2	-167.9	-17.4	616.5
Paper birch	281.0	32.0	13.4	3.7	-10.5	38.6	-13.8	-13.9	291.9
River birch	0.3	-	-	-	-	-	-	-	0.3
Black cherry	97.6	11.8	6.9	1.3	-2.4	17.6	-1.1	-0.7	113.4
Black walnut	0.2	-	-	-	-	-	-	-	0.2
Butternut	0.3	-	-	-	-	-	-0.1	-	0.2
Yellow poplar	-	-	-	-	-	-	-	-	-
Other hardwoods	2.7	1.0	0.9	0.2	-0.1	2.0	-0.9	-	3.8
Total	5,055.6	895.6	203.9	235.1	-260.4	1,074.2	-720.9	-89.2	5,319.7
All species	6,786.8	1,344.3	415.7	328.4	-335.2	1,753.2	-811.9	-103.0	7,625.1

(Table 9 continued on next page)

(Table 9 continued)

Southern lower peninsula

Species group	1980 growing stock volume 1/	Components							1987 growing stock volume
		Survivor growth	Ingrowth	Other growth 2/	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	13.2	1.6	-	-	-0.7	0.9	0.3	0.2	13.6
Red pine	51.1	16.9	1.4	1.7	-	20.0	4.6	-	66.5
White pine	67.4	17.7	1.0	1.1	-1.2	18.6	-	0.6	85.4
White spruce	1.8	2.4	-	-	-	2.4	-		4.2
Black spruce	-	-	-	-	-		-		
Balsam fir	0.2	-	-	-	-		-		0.2
Hemlock	7.1	1.3	-	-	-	1.3	-		8.4
Tamarack	3.8	0.7	1.7	0.1	-0.6	1.9	-	0.1	5.6
Eastern redcedar	0.5	0.1	-	-	-	0.1			0.6
Northern white-cedar	3.7	-	0.6	0.9	-	1.5			5.2
Other softwoods	23.5	6.0	2.0	2.2	-	10.2	-	-	33.7
Total	172.3	46.7	6.7	6.0	-2.5	56.9	-4.9	0.9	223.4
Hardwoods									
Select white oak	275.2	27.8	1.6	7.5	-0.3	36.6	-50.5	-6.7	254.6
Select red oak	330.9	46.1	1.9	14.1	-9.0	53.1	-83.3	-10.5	290.2
Other red oak	105.3	10.7	-	3.3	-8.2	5.8	-30.1	-2.7	78.3
Select hickory	60.4	7.9	2.4	1.6	-1.6	10.3	-4.2	-1.2	65.3
Other hickory	49.9	7.0	2.3	0.9	-2.0	8.2	-3.1	-1.0	54.0
Basswood	84.9	15.2	0.8	3.8	-1.6	18.2	-5.4	0.6	97.1
Beech	49.2	4.8	-	2.9	-1.7	6.0	9.6	0.3	45.3
Yellow birch	7.0	1.1	0.3	-	-	1.4	-	0.1	8.3
Hard maple	111.1	18.3	5.0	6.8	-2.9	27.2	-12.9	0.4	125.0
Soft maple	393.1	64.9	13.2	13.8	-13.1	78.8	-51.8	9.3	410.8
Elm	49.2	15.4	2.5	4.7	-2.3	20.3	-10.3	-1.0	58.2
Black ash	29.0	4.6	5.5	0.7	-2.1	8.7	-1.6	-1.2	34.9
White & green ash	202.2	35.2	19.0	8.8	-3.7	59.3	-22.7	-3.9	234.9
Sycamore	14.0	2.1	-	0.2	-0.8	1.5	-1.4	-0.1	14.0
Cottonwood	57.2	11.1	-	1.7	-0.2	12.6	-9.0	-2.1	58.7
Willow	26.0	3.6	0.3	0.7	-0.7	3.9	-4.2	-0.8	24.9
Hackberry	0.8	0.1	-	0.1	-0.3	-0.1	-	-0.1	0.6
Balsam poplar	10.4	3.4	0.3	1.0	-1.9	2.8	-	-1.1	12.1
Bigtooth aspen	79.5	20.1	1.2	4.3	-5.7	19.9	-14.6	-5.1	79.7
Quaking aspen	83.2	20.3	7.4	6.3	-4.1	29.9	-10.5	-5.1	97.5
Paper birch	20.8	4.1	3.6	0.9	-0.3	8.3	-1.8	-1.1	26.2
River birch	-	-	-	-	-	-	-		-
Black cherry	120.3	17.9	8.2	6.4	-2.0	30.5	-25.2	-2.0	123.6
Black walnut	26.8	1.7	0.9	0.5	-1.2	1.9	-2.3	0.8	25.6
Butternut	4.0	0.7	1.3	0.4	-	2.4	-0.4	-	6.0
Yellow poplar	16.6	2.0	-	0.4	-	2.4	-4.1	0.1	14.8
Other hardwoods	35.2	6.1	4.3	2.6	-2.3	10.7	-9.1	0.1	36.7
Total	2,242.2	352.2	82.0	94.4	-68.0	460.6	-368.1	-57.4	2,277.3
All species	2,414.5	398.9	88.7	100.4	-70.5	517.5	373.0	-58.3	2,500.7

1/ Figures have been adjusted from those published after the 1980 survey to conform to changes in survey definitions and procedures.
2/ Includes growth on ingrowth, mortality and removals.

Table 10.--Sawtimber volume and periodic growth on timberland by forest type and component of growth, Michigan, 1980-1987

(In million board feet 1/)

Forest tyep	1980 sawtimber volume 2/	Components							1987 sawtimber volume
		Survivor growth	Ingrowth	Other growth 3/	Mortality	Net growth	Removals	Other removals	
Jack pine	1,324.5	222.2	367.0	145.1	-107.4	626.9	-270.9	-36.9	1,643.6
Red pine	1,546.8	323.6	640.0	128.7	-25.4	1,066.9	-134.5	-	2,479.2
White pine	1,165.0	260.4	89.5	38.9	-18.9	369.9	-42.7	-24.4	1,467.8
Balsam fir	1,453.8	361.2	246.7	96.5	-86.3	618.1	-151.6	57.5	1,862.8
White spruce	265.3	74.3	70.8	33.7	-22.8	156.0	-35.1	-	386.2
Black spruce	492.4	89.1	83.3	31.3	-39.3	164.4	-35.9	-5.3	615.6
Northern white-cedar	2,732.0	278.6	296.7	102.3	-215.5	462.1	-216.1		2,978.0
Tamarack	89.9	13.5	19.9	5.2	-4.6	34.0	-6.9	-5.0	112.0
Oak-hickory	4,897.9	492.4	665.7	388.4	-128.4	1,418.1	-1,659.9	-141.4	4,514.7
Elm-ash-soft maple	3,224.9	386.4	420.7	131.0	-138.6	799.5	-430.9	141.4	3,452.1
Maple-birch	20,539.5	3,165.1	2,961.7	810.7	-870.7	6,066.8	-1,036.8	-	25,569.5
Aspen	5,506.2	989.7	1,400.0	959.1	-443.9	2,904.9	-1,990.5	-132.6	6,288.0
Paper birch	570.0	103.7	166.2	41.7	-36.9	274.7	-56.2	-7.3	781.2
Exotic	59.7	11.4	26.5	3.2	-1.9	39.2	-	-	98.9
Nonstocked	8.1	2.6	3.1	0.5	-	6.2	-	0.1	14.2
All types	43,876.0	6,774.2	7,457.8	2,916.3	-2,140.6	15,007.7	-6,068.0	551.9	52,263.8

1/ International 1/4 inch rule
2/ Figures have been adjusted from those published after the 1980 survey to conform to changes in survey definitions and procedures.
3/ Includes growth on ingrowth, mortality and removals.

Table 11.- Sawtimber volume and periodic growth on timberland by species group and component of growth, Michigan, 1980-1987

(In million board feet 1/)

Species group	1980 sawtimber volume 2/	Components							1987 sawtimber volume
		Survivor growth	Ingrowth	Other growth 3/	Mortality	Net growth	Removals	Other removals	
Softwoods									
Jack pine	1,331.8	199.9	390.2	144.1	-132.7	601.5	-279.2	-29.0	1,625.1
Red pine	1,975.2	409.3	769.1	194.4	-2.5	1,370.3	-321.2	-19.2	3,005.1
White pine	2,681.0	598.1	86.0	59.2	-24.0	719.3	-108.3	-39.6	3,252.4
White spruce	1,299.5	582.3	269.0	150.7	-45.3	956.7	-60.1	-19.1	2,177.0
Black spruce	358.8	47.9	50.1	33.2	-81.9	49.3	-29.6	-5.3	373.2
Balsam fir	1,068.4	271.7	296.1	107.8	-150.3	525.3	-71.7	-20.1	1,501.9
Hemlock	2,069.7	276.7	34.8	45.7	-62.5	294.7	-131.4	-6.2	2,226.8
Tamarack	194.7	21.7	23.0	8.0	-20.6	32.1	-17.9	-5.3	203.6
Eastern redcedar	3.7	1.0	-	-	-	1.0	-	-	4.7
Northern white-cedar	2,955.6	347.4	373.1	78.3	-85.3	713.5	-128.3	-25.5	3,515.3
Other softwoods	71.5	15.5	34.7	5.7	-	55.9	-	-0.3	127.1
Total	14,009.9	2,771.5	2,326.1	827.1	-605.1	5,319.6	-1,147.7	-169.6	18,012.2
Hardwoods									
Select white oak	1,507.1	123.6	99.2	51.3	-3.8	270.3	-265.5	-36.0	1,475.9
Select red oak	3,293.9	446.1	413.8	193.8	-74.7	979.0	-775.7	-74.6	3,422.6
Other red oak	688.9	59.0	76.4	46.0	-40.9	140.5	-238.0	-12.6	578.8
Select hickory	156.7	14.0	23.6	2.7	-4.7	35.6	-9.5	-3.4	179.4
Other hickory	132.0	9.4	27.3	3.0	-4.5	35.2	-9.4	-3.0	154.8
Basswood	1,534.4	282.6	344.2	78.7	-38.3	667.2	-66.9	-5.3	2,129.4
Beech	1,152.2	132.6	99.0	31.4	-26.3	236.7	-113.2	-0.8	1,274.9
Yellow birch	1,422.6	120.1	61.6	36.1	-192.9	24.9	-100.9	-4.7	1,341.9
Hard maple	5,987.4	923.6	833.0	233.9	-140.8	1,849.7	-384.7	-5.0	7,447.4
Soft maple	4,551.6	540.3	953.8	194.3	-158.6	1,529.8	-410.4	-69.8	5,601.2
Elm	514.8	66.5	61.9	42.3	-80.7	90.0	-102.5	-5.2	497.1
Black ash	338.6	21.0	72.8	9.2	-35.4	67.6	-17.8	-8.8	379.6
White & green ash	1,084.9	128.1	227.8	41.9	-23.5	374.3	-96.8	-14.9	1,347.5
Sycamore	57.1	10.0	1.7	1.6	-3.8	9.5	-5.5	-1.4	59.7
Cottonwood	223.6	29.3	25.8	12.9	-	68.0	-45.4	-8.1	238.1
Willow	115.1	13.4	9.1	3.0	-2.8	22.7	-12.8	-3.4	121.6
Hackberry	2.2	0.2	-	0.3	-1.3	-0.8	-	-	1.4
Balsam poplar	741.1	143.9	97.7	38.7	-89.0	191.3	-55.3	-12.8	864.3
Bigtooth aspen	1,697.4	261.8	522.3	410.6	-181.1	1,013.6	-816.9	-31.4	1,862.7
Quaking aspen	2,994.8	493.3	755.1	565.8	-372.2	1,442.0	-1,181.2	-59.6	3,196.0
Paper birch	838.8	102.8	254.8	45.6	-39.8	363.4	-85.6	-12.0	1,104.6
River birch	0.8	-	-	-	-	-	-	-	0.8
Black cherry	618.6	62.5	142.7	32.2	-15.3	222.1	-84.3	-5.7	750.7
Black walnut	91.3	7.2	14.4	2.3	-2.9	21.0	-7.9	-3.0	101.4
Butternut	11.3	0.9	3.6	0.9	-	5.4	-2.8	-0.2	13.7
Yellow poplar	66.5	5.1	3.9	2.8	-	11.8	-21.8	-0.3	56.2
Other hardwoods	42.4	5.4	6.2	7.9	-2.2	17.3	-9.5	-0.3	49.9
Total	29,866.1	4,002.7	5,131.7	2,089.2	-1,535.5	9,688.1	-4,920.3	-382.3	34,251.6
All species	43,876.0	6,774.2	7,457.8	2,916.3	-2,140.6	15,007.7	-6,068.0	-551.9	52,263.8

1/ International 1/4 inch rule
2/ Figures have been adjusted from those published after the 1980 survey to conform to changes in survey definitions and procedures.
3/ Includes growth on ingrowth, mortality and removals.

Table 12.--Net volume of growing stock on timberland by species group and forest type, Michigan, 1987

(In million cubic feet)

Species group	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white cedar
Softwoods								
Jack pine	669.8	491.3	63.4	4.9	0.8	0.7	21.8	
Red pine	1,196.8	76.5	912.2	30.7	1.9	0.6	8.8	2.3
White pine	671.1	14.6	39.2	214.6	35.1	8.8	20.2	42.0
White spruce	569.3	0.6	4.1	12.5	147.5	76.6	8.2	43.9
Black spruce	319.4	5.3	2.6	5.5	33.5	1.7	165.7	64.1
Balsam fir	871.0	1.7	5.9	7.7	244.5	9.9	25.9	112.2
Hemlock	555.6	-	1.6	2.2	9.5	0.1	1.8	14.4
Tamarack	103.3	0.1	0.3	0.6	5.4	0.4	14.1	30.9
Eastern redcedar	1.1	-	-	-	-	-	-	
Northern white-cedar	1,542.3	0.3	1.3	3.9	71.8	11.8	37.7	996.8
Other softwoods	87.2	-	4.0	13.4	0.1	3.7	0.1	2.8
Total	6,586.9	590.4	1,034.6	296.0	550.1	114.3	304.3	1,309.4
Hardwoods								
Select white oak	466.1	2.2	7.2	5.0	-	-	-	-
Select red oak	1,101.0	37.7	16.0	8.7	0.5	-	-	-
Other red oak	195.8	8.8	8.1	-	-	-	-	
Select hickory	66.1	-	-	-	-	-	-	
Other hickory	56.1	0.3	-	-	-	-	-	
Basswood	779.3	0.4	0.8	0.2	0.4			1.9
Beech	352.1	-	0.3	0.3	0.2	0.1	-	
Yellow birch	419.8	-	-	0.4	7.1	0.1	0.7	11.3
Hard maple	2,898.1	0.2	2.8	2.5	5.8	0.6	1.0	4.6
Soft maple	2,481.0	5.6	13.1	15.2	41.7	2.9	5.9	47.9
Elm	220.1	0.1	-	0.2	2.2	0.2	-	1.2
Black ash	279.1	-	-	-	5.1	-	2.3	30.4
White & green ash	507.7	-	0.2	-	0.2	-		2.3
Sycamore	14.8	-	-	-	-	-		
Cottonwood	69.7	-	-	-	-			
Willow	32.1	-	-	-	-	-		
Hackberry	0.6	-	-	-	-	-		
Balsam poplar	303.6	-	0.2	0.8	15.9	3.5	1.9	32.1
Bigtooth aspen	879.4	3.5	14.1	3.9	0.6	0.3	2.0	5.4
Quaking aspen	1,613.9	16.7	18.2	12.8	46.3	15.2	27.1	18.9
Paper birch	796.4	0.9	4.6	15.6	40.7	2.0	12.4	81.8
River birch	0.4	-	-	-	-	-		0.3
Black cherry	350.0	0.4	3.6	1.5	5.1	1.8	0.5	0.6
Black walnut	25.8	-	0.2	-	-	-		
Butternut	6.2	-	-	-	-	-		0.4
Yellow poplar	14.8	-	0.5	-	-	-		
Other hardwoods	40.7	0.2	-	-	-			
Total	13,970.7	77.0	89.9	67.1	171.8	26.7	53.8	239.1
All species	20,557.6	667.4	1,124.5	363.1	721.9	141.0	358.1	1,548.5

(Table 12 continued on next page)

(Table 12 continued)

Species group	Tamarack	Oak-hickory	Elm-ash-soft maple	Maple-birch	Aspen	Paper birch	Exotic	Nonstocked
Softwoods								
Jack pine	0.8	44.3	-	14.9	22.7	2.6	0.9	0.7
Red pine	0.2	44.2	3.3	40.0	58.2	5.7	11.2	1.0
White pine	1.6	35.2	20.3	156.3	70.2	10.2	2.5	0.3
White spruce	0.1	0.7	15.4	126.9	114.7	18.1		
Black spruce	5.8	0.2	7.1	10.6	14.8	2.4	-	0.1
Balsam fir	2.4	1.0	35.0	208.9	185.9	29.6		0.4
Hemlock	-	1.5	18.4	490.1	11.8	4.2		
Tamarack	36.0	-	5.6	2.5	5.0	2.1		0.3
Eastern redcedar	-	0.6	-	0.5	-		-	
Northern white-cedar	7.5	0.5	85.2	153.5	134.7	37.0	0.1	0.2
Other softwoods	-	1.6	0.4	13.8	0.9	-	46.4	
Total	54.4	129.8	190.7	1,218.0	618.9	111.9	61.1	3.0
Hardwoods								
Select white oak	-	335.9	24.5	69.2	21.3	0.8		
Select red oak	-	638.5	14.3	242.7	134.4	7.0	1.1	0.1
Other red oak	-	157.3	2.5	15.0	3.8	-	0.3	-
Select hickory	-	38.3	2.6	24.7	0.5	-	-	
Other hickory	-	30.0	0.6	25.0	-	0.2		
Basswood	-	9.0	24.7	716.0	18.9	6.4	0.6	
Beech	-	3.4	3.3	335.7	8.1	0.7	-	
Yellow birch	-	0.7	18.8	372.3	6.2	2.1	0.1	
Hard maple	-	5.6	13.3	2,796.1	52.7	12.5	0.4	
Soft maple	0.1	118.9	473.3	1,403.2	306.3	45.7	0.6	0.6
Elm	-	1.9	42.8	158.1	11.6	1.3	0.1	0.4
Black ash	0.4	3.1	146.6	63.8	22.3	4.7	-	0.4
White & green ash	-	13.1	100.5	355.0	30.9	5.3	0.1	0.1
Sycamore	-	-	9.9	4.9		-		
Cottonwood	-	3.4	36.3	23.3	6.7			
Willow	-	1.6	22.0	7.0	1.5			
Hackberry	-	-	0.6	-	-			
Balsam poplar	1.2	0.7	18.8	26.2	193.0	8.0	1.0	0.3
Bigtooth aspen		101.0	8.1	201.8	527.1	11.1	0.5	
Quaking aspen	1.4	25.3	62.6	383.0	949.9	33.3	2.8	0.4
Paper birch	1.9	11.2	40.3	155.3	212.2	216.8		0.7
River birch	-	-	-	0.1				
Black cherry	-	32.4	24.8	240.9	35.5	1.7	0.8	0.4
Black walnut	-	15.3	3.4	6.9				
Butternut	-	3.1	0.8	1.9				
Yellow poplar		0.7	1.2	12.4	-	-		-
Other hardwoods	-	1.8	9.0	28.6	1.0	0.1		-
Total	5.0	1,552.2	1,105.6	7,669.1	2,543.9	357.7	8.4	3.4
All species	59.4	1,682.0	1,296.3	8,887.1	3,162.8	469.6	69.5	6.4

Table 13.--Net volume of sawtimber on timberland by species group and forest type, Michigan, 1987

(In million board feet) 1/

Species group	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar
Softwoods								
Jack pine	1,625.1	1,140.2	146.9	17.9	1.2	1.5	75.0	-
Red pine	3,005.1	295.3	1,951.1	152.8	9.5	1.4	37.2	13.4
White pine	3,252.4	66.3	169.5	1,055.1	180.1	40.3	104.8	219.5
White spruce	2,177.0	3.5	12.3	46.1	590.3	239.8	33.0	151.4
Black spruce	373.2	7.1	5.0	8.3	57.8	2.1	134.4	79.5
Balsam fir	1,501.9	6.5	10.9	16.1	432.3	20.5	43.6	105.3
Hemlock	2,226.8	-	4.3	9.0	33.2	0.4	5.7	51.0
Tamarack	203.6	-	1.0	2.8	17.6	1.3	17.8	52.0
Eastern redcedar	4.7	-	-	-	-	-	-	-
Northern white-cedar	3,515.3	-	1.4	9.2	219.6	31.0	106.8	1,905.7
Other softwoods	127.1	-	8.3	24.3	-	1.9	-	1.2
Total	18,012.2	1,518.9	2,310.7	1,341.6	1,541.6	340.2	558.3	2,579.0
Hardwoods								
Select white oak	1,475.9	6.9	25.6	20.0	-	-	-	-
Select red oak	3,422.6	83.8	57.7	21.5	1.2	-	-	-
Other red oak	578.8	15.9	23.5	-	-	-	-	-
Select hickory	179.4	-	-	-	-	-	-	-
Other hickory	154.8	1.4	-	-	-	-	-	-
Basswood	2,129.4	1.2	2.2	-	1.5	-	-	5.6
Beech	1,274.9	-	1.5	-	0.7	0.6	-	-
Yellow birch	1,341.9	-	-	0.9	25.1	-	1.7	33.9
Hard maple	7,447.4	-	2.0	3.3	13.2	0.7	2.4	11.2
Soft maple	5,601.2	3.7	15.6	16.3	81.7	3.0	5.5	89.0
Elm	497.1	-	-	-	1.1	0.6	-	1.6
Black ash	379.6	-	-	-	4.6	-	1.3	13.3
White & green ash	1,347.5	-	-	-	-	-	-	3.9
Sycamore	59.7	-	-	-	-	-	-	-
Cottonwood	238.1	-	-	-	-	-	-	-
Willow	121.6	-	-	-	-	-	-	-
Hackberry	1.4	-	-	-	-	-	-	-
Balsam poplar	864.3	-	0.7	1.4	45.2	11.0	2.7	86.5
Bigtooth aspen	1,862.7	6.0	19.6	8.5	1.5	1.3	1.3	17.4
Quaking aspen	3,196.0	5.8	6.3	18.2	78.6	22.9	21.6	44.9
Paper birch	1,104.6	-	7.9	33.4	61.1	1.8	20.8	87.7
River birch	0.8	-	-	-	-	-	-	0.8
Black cherry	750.7	-	5.9	2.7	5.7	4.1	-	0.7
Black walnut	101.4	-	-	-	-	-	-	-
Butternut	13.7	-	-	-	-	-	-	2.5
Yellow poplar	56.2	-	-	-	-	-	-	-
Other hardwoods	49.9	-	-	-	-	-	-	-
Total	34,251.6	124.7	168.5	126.2	321.2	46.0	57.3	399.0
All species	52,263.8	1,643.6	2,479.2	1,467.8	1,862.8	386.2	615.6	2,978.0

(Table 13 continued on next page)

(Table 13 continued)

Species group	Tamarack	Oak-hickory	Elm-ash-soft maple	Maple-birch	Aspen	Paper birch	Exotic	Nonstocked
Softwoods								
Jack pine	2.8	114.2	-	33.6	69.8	16.0	4.0	2.0
Red pine	1.3	133.5	20.2	139.1	212.7	16.1	19.4	2.1
White pine	7.0	156.5	100.9	761.9	336.0	44.8	8.9	0.8
White spruce	-	1.1	64.3	541.5	420.6	73.0		0.1
Black spruce	8.3	-	15.9	30.5	20.8	2.8		0.2
Balsam fir	2.7	1.6	51.1	453.4	315.6	40.7		1.6
Hemlock	-	5.2	59.4	2,010.5	34.8	13.3		
Tamarack	67.5	-	14.1	10.5	15.8	1.5		1.7
Eastern redcedar	-	3.9	-	0.8	-			
Northern white-cedar	15.5	1.7	225.4	615.8	308.1	74.6		0.5
Other softwoods	-	9.1	1.4	22.2	0.8	-	57.9	
Total	105.1	426.8	552.7	4,619.8	1,735.0	282.8	90.2	9.5
Hardwoods								
Select white oak	-	996.6	98.6	256.8	68.1	3.3		
Select red oak	-	1,829.6	51.7	937.0	413.6	24.8	1.1	0.6
Other red oak	-	467.1	7.8	56.4	8.1		-	
Select hickory	-	89.3	7.5	81.0	1.6			
Other hickory	-	86.1	1.3	65.1	-	0.9		
Basswood	-	16.9	75.9	1,967.4	42.6	16.1		
Beech	-	7.2	10.1	1,246.2	8.2	0.4		
Yellow birch	-	1.0	43.5	1,224.8	7.5	2.8	0.7	
Hard maple	-	12.5	30.3	7,283.1	63.3	23.5	1.9	
Soft maple	-	156.9	1,403.9	3,418.0	348.8	54.8	1.6	2.4
Elm	-	1.5	62.8	416.1	11.5	1.9		
Black ash	-	1.5	222.5	120.0	15.4	1.0		
White & green ash	-	30.8	263.0	991.0	51.2	7.0	0.6	
Sycamore	-	-	41.4	18.3	-	-		
Cottonwood	-	14.6	114.2	82.3	27.0			
Willow	-	6.7	79.4	29.9	5.6		-	
Hackberry	-	-	1.4	-				
Balsam poplar	3.5	2.9	60.9	81.5	542.3	24.9	-	0.8
Bigtooth aspen	-	181.0	25.8	571.2	1,001.3	27.6		0.2
Quaking aspen	2.2	23.5	144.0	1,093.6	1,657.9	74.9	0.9	0.7
Paper birch	1.2	10.5	62.0	355.2	229.3	233.7		
River birch	-	-	-	-				
Black cherry	-	71.0	57.5	551.5	49.7	-	1.9	
Black walnut	-	72.5	11.2	17.7		-		
Butternut	-	4.1	4.2	2.9			-	
Yellow poplar	-	4.1	6.3	45.8			-	
Other hardwoods	-	-	12.2	36.9	-	0.8	-	
Total	6.9	4,087.9	2,899.4	20,949.7	4,553.0	498.4	8.7	4.7
All species	112.0	4,514.7	3,452.1	25,569.5	6,288.0	781.2	98.9	14.2

1/ International 1/4-inch rule

Table 14.--Net volume of growing stock on timberland by species group and diameter class, Michigan, 1987

(In million cubic feet)

Species group	All classes	Diameter class (inches at breast height) 5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods												
Jack pine	669.8	150.2	218.1	182.9	75.1	22.4	14.0	4.0	3.1			
Red pine	1,196.8	326.4	355.8	201.7	103.7	77.4	48.4	37.2	25.6	13.0	7.1	0.5
White pine	671.1	23.5	38.9	58.7	61.4	86.5	89.0	82.7	72.4	50.6	85.7	21.7
White spruce	569.3	46.1	80.9	100.6	111.2	90.4	67.3	38.0	20.2	8.5	5.6	0.5
Black spruce	319.4	148.9	92.3	47.2	14.9	6.9	3.1	1.4	4.7		-	
Balsam fir	871.0	287.5	254.6	170.1	96.0	47.0	11.4	3.6	0.6		0.2	
Hemlock	555.6	17.7	40.4	55.5	72.2	88.8	84.8	70.9	45.3	33.6	40.3	6.1
Tamarack	103.3	41.7	26.1	19.2	9.2	3.8	1.8	0.7	0.4	0.3	0.1	
Eastern redcedar	1.1	-	0.4	-	0.2	0.3	0.2	-	-			
Northern white-cedar	1,542.3	444.6	429.0	295.8	167.7	104.0	51.7	27.0	12.0	6.0	3.9	0.6
Other softwoods	87.2	35.5	27.7	15.0	5.4	2.6	0.8	-		0.2		-
Total	6,586.9	1,522.1	1,564.2	1,146.7	717.0	530.1	372.5	265.5	184.3	112.2	142.9	29.4
Hardwoods												
Select white oak	466.1	37.5	57.0	70.8	65.8	51.6	49.5	37.9	31.9	19.1	29.2	15.8
Select red oak	1,101.0	73.3	152.1	190.4	182.8	149.2	118.7	90.0	56.1	28.9	45.4	14.1
Other red oak	195.8	11.7	22.1	40.0	42.3	26.7	17.2	12.6	10.8	4.4	7.1	0.9
Select hickory	66.1	7.5	11.2	11.8	12.0	7.8	7.7	4.5	1.6	1.0	1.0	
Other hickory	56.1	5.8	8.7	10.6	11.8	6.3	3.7	4.3	1.4	0.4	2.1	1.0
Basswood	779.3	55.1	110.6	157.6	160.9	114.0	73.3	50.7	31.0	12.3	11.3	2.5
Beech	352.1	30.5	37.3	42.9	41.7	52.8	54.9	35.8	24.9	14.9	13.8	2.6
Yellow birch	419.8	41.7	56.4	58.5	52.0	54.5	56.6	39.0	26.1	16.1	14.6	4.3
Hard maple	2,898.1	469.1	490.3	453.4	381.8	328.7	280.8	218.5	143.4	66.6	51.3	14.2
Soft maple	2,481.0	466.6	508.3	444.2	338.9	254.4	178.4	108.3	65.5	39.6	55.2	21.6
Elm	220.1	27.1	44.5	38.8	31.2	31.8	21.9	11.3	7.4	3.3	2	
Black ash	279.1	113.2	68.7	37.8	29.6	18.0	5.7	2.9	1.5	0.9	0.7	
White & green ash	507.7	86.8	79.1	83.8	82.0	58.4	46.5	28.8	18.6	12.4	10.3	1
Sycamore	14.8	0.2	0.8	1.4	1.4		0.6	1.8	0.4	2.8	1.3	
Cottonwood	69.7	2.0	3.3	8.1	9.2	8.8	11.8	4.5	4.5	4.6	5.1	
Willow	32.1	0.1	0.2	2.5	4.1	5.4	3.5	4.4	1.2	1.5	1.3	
Hackberry	0.6	0					0.3					
Balsam poplar	302.6	22	38.4	46.1	52.9	46.8	41.3	22.2	11.9	10.4	3.6	
Bigtooth aspen	879.4	83	165.6	213.1	208.2	114.2	49.7	21.6	10.2	3.5	1.1	
Quaking aspen	1,612.9	274	342.2	359.1	296.0	175.1	93.2	43.5	16.6	9.6	2.5	
Paper birch	796.4	205	226.3	167.1	112.8	49.5	25.2	9.5	3.2	1.1	0.4	
River birch	0.4					0.2						
Black cherry	350.0	61	79.1	72.3	51.6	34.3	12.4	7.1	2.0	5.4	1.3	
Black walnut	25.8	1	3.3	2.3	2	2.2	4.6	1.5	1.4	0.6	0.4	
Butternut	6.2	2	1	0.4	0.2	0.9	0.1	0.1				
Yellow poplar	15.9	2	2	1	2	2.3	1	0.1	0.3	0.6	0.3	
Other hardwoods	47.7	14	9.1	4	2	2	1	0.1	0.2	0.5	0.3	
Total	13,400	2,115	2,519	2,442	2,111	1,982.6	1,170.9	761.9	484.2	260.5	273.5	77
All species	20,000	3,937.1	4,083.4	3,589.1	2,828	2,513.1	1,543	1,027.4	668.5	372.7	416.4	107

Table 15.--Net volume of sawtimber on timberland
by species group and diameter class, Michigan, 1987

(In million board feet) 1/

Species group	All classes	Diameter class (inches at breast height) 9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods										
Jack pine	1,525.1	981.0	408.3	122.6	75.1	21.1	17.0	-		
Red pine	3,005.1	1,187.9	606.4	443.6	277.0	216.5	151.0	77.0	43.1	2.6
White pine	3,252.4	241.4	309.9	443.3	466.2	445.6	404.1	290.8	511.1	140.0
White spruce	2,177.0	450.9	533.2	449.8	349.3	202.7	108.4	48.3	31.5	2.9
Black spruce	373.2	218.6	71.6	33.0	15.4	7.9	26.7	-	-	-
Balsam fir	1,501.9	767.3	436.0	220.0	55.4	18.8	3.3	-	1.1	-
Hemlock	2,226.8	187.5	304.5	418.3	406.8	326.2	211.6	154.8	188.3	28.8
Tamarack	203.6	109.8	52.9	22.4	10.2	4.2	1.8	1.7	0.6	-
Eastern redcedar	4.7	-	1.3	2.1	1.3	-	-	-	-	-
Northern white-cedar	3,515.3	1,443.8	890.7	578.9	305.4	159.9	72.7	34.3	25.4	4.2
Other softwoods	127.1	78.9	28.4	14.6	4.4	-	-	0.8	-	-
Total	18,012.2	5,667.1	3,643.2	2,748.6	1,966.5	1,402.9	996.6	607.7	801.1	178.5
Hardwoods										
Select white oak	1,475.9	-	350.3	252.0	235.2	179.0	150.3	90.6	140.2	78.3
Select red oak	3,422.6	-	916.2	735.7	583.7	447.6	282.6	147.2	235.4	74.2
Other red oak	578.8	-	198.4	127.0	80.5	60.4	52.2	21.8	34.4	4.1
Select hickory	179.4	-	64.2	40.3	36.7	20.5	7.7	5.0	5.0	-
Other hickory	154.8	-	60.9	31.5	17.3	21.1	7.3	1.7	9.8	5.2
Basswood	2,129.4		746.0	529.7	337.6	240.5	145.2	61.3	55.8	13.3
Beech	1,274.9	-	236.0	283.6	282.8	178.4	130.3	78.8	72.5	12.5
Yellow birch	1,341.9	-	245.8	274.5	293.9	202.9	135.5	87.1	80.0	22.2
Hard maple	7,447.4	-	1,921.4	1,640.7	1,399.4	1,083.7	723.7	336.0	266.5	76.0
Soft maple	5,601.2	-	1,979.8	1,351.6	902.4	521.8	310.2	183.4	252.8	99.2
Elm	497.1		146.2	145.7	96.8	50.6	32.0	14.2	9.1	2.5
Black ash	379.6	-	201.6	111.3	35.1	16.5	7.8	4.2	3.1	-
White & green ash	1,347.5	-	470.0	309.5	230.4	138.3	89.4	57.1	48.1	4.7
Sycamore	59.7	-	6.1	-	2.6	7.9	2.0	13.5	9.8	17.8
Cottonwood	238.1	-	38.4	35.2	49.0	19.3	20.1	19.5	26.3	30.3
Willow	121.6	-	16.9	22.3	14.4	18.1	7.5	6.7	23.3	12.4
Hackberry	1.4	-	-	-	1.4	-	-	-	-	-
Balsam poplar	864.3	-	220.8	202.4	181.6	102.6	83.5	49.7	23.7	-
Bigtooth aspen	1,862.7	-	921.5	520.5	231.9	104.4	50.2	18.9	15.3	-
Quaking aspen	3,196.0	-	1,419.6	890.4	485.7	235.3	92.6	52.0	20.4	-
Paper birch	1,104.6	-	612.3	273.6	133.7	51.5	20.1	7.1	6.3	-
River birch	0.8	-	-	0.8	-	-	-	-	-	-
Black cherry	750.7	-	320.5	193.6	130.9	37.8	26.2	27.5	12.5	1.7
Black walnut	101.4	-	25.4	23.9	27.3	8.3	8.0	3.4	5.1	-
Butternut	13.7	-	3.8	4.9	3.8	1.2		-	-	-
Yellow poplar	56.2	-	7.7	17.1	10.3	6.3	10.0	3.4	1.4	-
Other hardwoods	49.9	-	15.4	17.6	11.6	-	1.0	2.7	1.6	-
Total	34,251.6	-	11,145.2	8,035.4	5,816.0	3,754.0	2,395.4	1,292.8	1,358.4	454.4
All species	52,263.8	5,667.1	14,788.4	10,784.0	7,782.5	5,156.9	3,392.0	1,900.5	2,159.5	632.9

1/ International 1/4-inch rule

Table 16 Annual net growth, mortality and removals of growing stock and sawtimber on timberland by softwoods and hardwoods, Michigan, 1979 and 1986

Net growth

Species group	Growing stock		Sawtimber	
	1979	1986	1979	1986
	Million cubic feet		Million board feet 1/	
Softwoods	205.5	231.8	686.9	957.0
Hardwoods	472.3	521.2	1,697.5	1,689.8
All species	677.8	753.0	2,384.4	2,646.7

Mortality

Softwoods	41.1	42.7	80.8	94.5
Hardwoods	117.1	75.7	259.4	188.2
All species	158.2	118.4	340.2	282.7

Removals

Softwoods	56.4	71.9	165.2	284.0
Hardwoods	218.2	325.7	750.3	836.0
All species	274.6	397.6	915.5	1120.0

1/ International 1/4 inch rule

Table 17.--Net volume in short-log trees on timberland by species group and diameter class, Michigan, 1987

(In million cubic feet)

Species group	All classes	Diameter class (inches at breast height) 9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods										
Jack pine	5.2	2.8	0.9	1.0	0.4	0.1	-	-	-	-
Red pine	1.3	0.4	0.6	0.1	-	0.2	-	-	-	
White pine	6.7	0.8	1.7	1.8	1.0	0.2	0.4	0.4	0.4	-
White spruce	2.2	0.2	1.0	0.4	0.4	-	0.2	-	-	-
Black spruce	0.6	0.4	0.2	-	-	-	-	-	-	-
Balsam fir	4.1	0.4	2.2	1.0	-	0.2	0.3	-	-	-
Hemlock	12.3	2.3	2.1	2.6	1.3	1.1	1.2	0.3	1.3	0.1
Tamarack	0.8	0.4	0.3	-	-	0.1	-	-	-	
Northern white-cedar	33.7	8.9	9.8	5.7	3.5	2.3	1.5	0.8	1.0	0.2
Other softwoods	0.8	0.4	-	0.4	-	-	-	-	-	-
Total	67.7	17.0	18.8	13.0	6.6	4.2	3.6	1.5	2.7	0.3
Hardwoods										
Select white oak	6.0	-	1.5	0.9	1.1	0.1	0.2	0.9	0.7	0.6
Select red oak	14.7	-	2.1	4.2	2.3	1.9	1.6	0.4	1.4	0.8
Other red oak	2.0	-	0.4	0.9	0.5	-	-	0.1		0.1
Select hickory	0.6	-	0.3	-	-	-	-	0.3	-	
Basswood	7.8	-	1.5	1.9	1.2	1.0	1.1	0.5	0.4	0.2
Beech	12.7	-	0.7	3.2	0.7	1.0	2.2	1.2	2.7	1.0
Yellow birch	22.8	-	3.6	4.4	3.8	2.3	2.9	1.7	3.2	0.9
Hard maple	49.1	-	8.2	10.6	7.8	5.2	5.2	2.9	6.4	2.8
Soft maple	35.1	-	6.2	7.8	5.4	5.4	2.9	1.7	3.7	2.0
Elm	4.2	-	1.2	1.9	0.4	0.3	0.3	-	-	0.1
Black ash	0.8	-	0.3	0.2	0.1	0.2	-	-	-	
White & green ash	6.9	-	1.5	1.6	0.9	0.8	0.4	-	1.6	0.1
Cottonwood	0.2	-	-	-	-		-	-	0.2	-
Willow	2.4	-	0.3	0.3	0.8	-	0.2	-	-	0.8
Balsam poplar	1.5	-	0.5	0.4	0.2	0.1	0.2	0.1	-	-
Bigtooth aspen	10.0	-	1.0	3.2	2.4	1.8	0.7	0.3	0.6	-
Quaking aspen	20.2	-	3.0	6.5	5.6	2.8	0.8	0.9	0.6	-
Paper birch	7.9	-	2.5	2.4	1.1	0.3	1.2	0.4	-	-
Black cherry	6.1	-	1.6	1.9	1.2	0.6	0.4	0.4	-	-
Black walnut	0.3	-	-	-	-	-	-	-	-	0.3
Other hardwoods	0.7	-	-	0.7	-	-	-	-	-	-
Total	212.0	-	36.4	53.0	35.5	23.8	20.3	11.8	21.5	9.7
All species	279.7	17.0	55.2	66.0	42.1	28.0	23.9	13.3	24.2	10.0

Table 18.--Net volume in short-log trees on timberland by species group and diameter class, Michigan, 1987

(In million board feet) 1/

Species group	All classes	Diameter class(inches at breast height) 9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-28.9	29.0+
Softwoods										
Jack pine	17.4	9.1	3.5	3.2	1.3	0.3	-	-	-	-
Red pine	5.5	1.5	2.6	0.6	-	0.8	-	-	-	-
White pine	22.9	2.3	5.4	6.3	3.4	1.0	1.6	1.6	1.3	-
White spruce	9.7	1.1	4.5	1.7	1.6	-	0.8	-	-	-
Black spruce	2.0	1.4	0.6	-	-	-	-	-	-	-
Balsam fir	11.3	1.1	6.0	2.7	-	0.5	1.0	-	-	-
Hemlock	28.8	4.0	4.0	6.0	3.4	2.8	3.5	1.1	3.6	0.4
Tamarack	3.6	1.8	1.3	-	-	0.5	-	-	-	-
Northern white-cedar	115.2	27.7	33.1	19.7	12.1	8.1	6.2	3.0	4.4	0.9
Other softwoods	3.8	2.0	-	1.8	-	-	-	-	-	-
Total	220.2	52.0	61.0	42.0	21.8	14.0	13.1	5.7	9.3	1.3
Hardwoods										
Select white oak	15.5	-	4.4	2.2	2.8	0.4	0.4	2.0	1.7	1.6
Select red oak	33.0	-	4.4	9.3	5.2	4.1	3.7	0.9	3.6	1.8
Other red oak	4.4	-	1.0	1.8	1.2	-	-	0.2	-	0.2
Select hickory	1.5	-	0.8	-	-	-	-	0.7	-	-
Basswood	16.7	-	3.2	4.1	2.6	2.3	2.3	1.0	0.8	0.4
Beech	37.0	-	2.2	9.8	2.1	3.1	6.5	3.5	7.4	2.4
Yellow birch	61.5	-	7.5	10.9	10.5	6.8	7.8	5.4	10.0	2.6
Hard maple	133.2	-	22.3	28.1	21.1	13.8	14.0	8.2	17.8	7.9
Soft maple	101.6	-	20.2	24.0	15.7	14.7	7.6	4.6	9.9	4.9
Elm	10.4	-	3.1	4.8	0.8	0.7	0.7	-	-	0.3
Black ash	2.1	-	0.8	0.6	0.3	0.4	-	-	-	-
White & green ash	16.6	-	4.1	4.0	2.2	1.7	1.1	-	3.2	0.3
Cottonwood	0.6	-	-	-	-	-	-	-	0.6	-
Willow	7.5	-	0.9	0.7	2.6	-	0.7	-	-	2.6
Balsam poplar	4.2	-	1.2	1.1	0.5	0.4	0.6	0.4	-	-
Bigtooth aspen	17.1	-	1.7	5.5	3.7	3.2	1.3	0.6	1.1	-
Quaking aspen	50.6	-	6.7	16.0	14.5	7.6	1.9	2.4	1.5	-
Paper birch	22.9	-	6.8	6.5	3.3	1.0	3.9	1.4	-	-
Black cherry	16.8	-	4.7	5.5	3.2	1.6	0.9	0.9	-	-
Black walnut	0.8	-	-	-	-	-	-	-	-	0.8
Other hardwoods	2.2	-	-	2.2	-	-	-	-	-	-
Total	556.2	-	96.0	137.1	92.3	61.8	53.4	32.2	57.6	25.8
All species	776.4	52.0	157.0	179.1	114.1	75.8	66.5	37.9	66.9	27.1

1/ International 1/4-inch rule

Table 19.--All live tree biomass on timberland
by species group and tree biomass component, Michigan, 1987

All units

Species group	All components	Component				1- to 5-inch trees	Average weight per cubic foot (including bark)
		Growing stock		Cull			
		Bole	Tops and limbs	Bole	Tops and limbs		
	Green tons						Pounds
Softwoods							
Jack pine	29,135,668	18,474,920	3,753,315	1,229,387	252,410	5,425,636	46
Red pine	44,080,850	32,820,688	6,358,041	473,292	92,203	4,336,626	46
White pine	24,229,261	18,227,989	3,176,358	907,941	171,615	1,745,358	45
White spruce	21,394,126	14,316,222	5,155,248	235,136	87,734	1,599,786	45
Black spruce	18,852,847	8,340,447	3,550,576	132,795	55,627	6,773,402	45
Balsam fir	56,020,581	24,153,300	10,369,627	664,784	270,017	20,562,853	47
Hemlock	27,597,475	17,801,289	5,713,172	1,882,422	631,191	1,569,401	51
Tamarack	6,718,088	3,345,879	732,028	340,318	74,003	2,225,860	52
Eastern redcedar	160,734	29,536	10,774	-	-	120,424	43
Northern white-cedar	73,866,303	31,894,161	14,323,924	5,823,254	2,458,446	19,366,518	36
Other softwoods	5,555,165	2,101,680	939,103	423,584	186,109	1,904,689	44
Total	307,611,098	171,506,111	54,082,166	12,112,913	4,279,355	65,630,553	43
Hardwoods							
Select white oak	27,845,526	16,981,532	6,992,591	1,068,280	422,860	2,380,263	58
Other white oak	6,129	-	-	4,003	2,126	-	58
Select red oak	63,940,926	42,731,451	16,659,603	2,311,208	888,036	1,350,628	64
Other red oak	12,080,218	7,704,269	3,116,177	738,134	328,300	193,338	64
Select hickory	3,773,321	2,494,949	1,009,548	66,778	22,981	179,065	63
Other hickory	2,971,870	1,947,995	779,883	55,224	22,226	166,542	59
Basswood	30,765,863	19,987,063	8,033,359	1,144,674	449,042	1,151,725	42
Beech	22,943,511	12,487,183	4,790,723	2,986,761	1,104,020	1,574,824	59
Yellow birch	32,834,883	16,479,188	6,624,680	5,094,567	1,887,984	2,748,464	61
Hard maple	204,447,796	114,213,364	46,680,988	10,766,058	4,165,604	28,621,782	63
Soft maple	151,657,303	85,753,185	35,564,045	8,520,506	3,308,106	18,511,461	55
Elm	15,527,011	7,515,892	3,345,490	894,239	397,277	3,374,113	55
Black ash	21,157,053	8,839,864	4,219,735	953,641	464,138	6,679,675	50
White & green ash	26,433,344	15,885,509	6,493,383	752,400	289,936	3,012,116	51
Sycamore	677,587	503,482	156,747	13,869	3,489		58
Cottonwood	3,279,553	2,171,257	799,215	60,979	20,124	227,978	51
Willow	1,798,378	933,320	328,936	279,796	91,472	164,854	48
Hackberry	30,635	19,316	9,095	-	-	2,224	52
Balsam poplar	15,812,691	9,919,666	3,698,999	684,902	249,873	1,259,251	53
Bigtooth aspen	42,777,459	27,370,476	8,447,747	2,655,495	790,115	3,513,626	50
Quaking aspen	92,030,605	51,997,775	17,010,526	7,838,423	2,465,687	12,718,194	50
Paper birch	49,173,256	28,373,176	12,530,558	2,566,238	1,111,641	4,591,643	55
River birch	74,910	12,482	5,909	33,527	11,319	11,673	55
Black cherry	22,237,080	10,612,462	4,494,640	2,619,735	1,139,414	3,370,829	49
Black walnut	1,375,984	929,320	362,522	41,629	13,996	28,517	54
Butternut	312,775	168,482	73,781	16,206	5,484	48,822	45
Yellow poplar	710,737	474,730	177,884	-	-	58,123	52
Other hardwoods	3,578,608	1,188,729	557,256	271,411	123,135	1,438,077	46
Noncommercial spp.	9,146,873	161,744	78,953	2,037,798	1,028,078	5,840,300	50
Total	859,401,885	487,857,861	193,042,973	54,476,481	20,806,463	103,218,107	56
All species	1,167,012,983	659,363,972	247,125,139	66,589,394	25,085,818	168,848,660	52

(Table 19 continued on next page)

(Table 19 continued)

Northern lower peninsula

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops and limbs	Bole	Tops and limbs		
		Green tons					Pounds
Softwoods							
Jack pine	18,138,636	10,638,985	2,195,558	914,362	190,401	4,199,330	46
Red pine	30,405,606	22,783,609	4,449,642	306,518	60,130	2,805,707	46
White pine	8,481,891	5,927,596	1,068,440	249,357	49,084	1,187,414	45
White spruce	2,185,116	1,381,229	526,617	48,399	22,790	206,081	45
Black spruce	1,824,538	892,526	368,616	29,520	12,449	521,427	45
Balsam fir	7,064,849	3,098,204	1,343,705	89,189	41,073	2,492,678	47
Hemlock	4,044,587	2,433,899	843,442	204,613	71,759	490,874	51
Tamarack	1,825,005	798,152	172,360	132,814	29,821	691,858	52
Eastern redcedar	18,709	10,836	3,497	-	-	4,376	43
Northern white-cedar	24,242,843	10,814,034	4,979,531	1,395,061	606,375	6,447,842	36
Other softwoods	3,438,324	1,196,448	554,537	273,055	123,533	1,290,751	44
Total	101,670,104	59,975,518	16,505,945	3,642,888	1,207,415	20,338,338	43
Hardwoods							
Select white oak	13,631,077	7,685,857	3,409,487	687,744	283,475	1,564,514	58
Other white oak	6,129	-	-	4,003	2,126	-	58
Select red oak	41,131,999	26,998,959	10,764,435	1,668,717	655,291	1,044,597	64
Other red oak	7,534,412	4,588,033	1,925,520	656,273	292,361	72,225	64
Select hickory	41,429	29,362	12,067	-	-	-	63
Other hickory	144,311	72,040	32,242	-	-	40,029	59
Basswood	14,216,612	9,663,719	3,886,788	329,932	129,450	206,723	42
Beech	9,127,393	4,900,236	1,910,100	1,165,456	416,779	734,822	59
Yellow birch	2,571,772	1,317,522	573,288	302,843	126,499	251,620	61
Hard maple	49,966,122	28,219,217	11,891,400	1,769,528	673,285	7,412,692	63
Soft maple	50,420,309	29,078,883	12,237,186	1,834,905	711,231	6,558,104	55
Elm	2,109,498	803,703	365,003	196,011	98,580	646,201	54
Black ash	7,192,702	2,840,345	1,384,469	409,899	203,903	2,354,086	50
White & green ash	10,414,499	6,474,328	2,637,745	274,480	107,797	920,149	51
Sycamore	36,181	27,948	8,233	-	-	-	58
Cottonwood	445,811	312,883	116,069	12,062	4,797	-	51
Willow	450,841	217,466	78,639	30,856	10,094	113,786	48
Hackberry	-	-	-	-	-	-	-
Balsam poplar	5,655,923	3,574,661	1,288,260	289,199	103,696	400,107	53
Bigtooth aspen	31,234,436	19,569,021	6,063,487	1,897,555	565,695	3,138,678	50
Quaking aspen	36,389,484	19,533,311	6,450,650	2,478,193	803,388	7,123,942	50
Paper birch	16,229,503	9,514,347	4,243,289	729,188	314,780	1,427,899	55
River birch	14,372	9,925	4,447	-	-	-	55
Black cherry	7,525,659	3,358,229	1,416,810	1,116,003	486,328	1,148,289	49
Black walnut	10,401	7,430	2,971	-	-	-	54
Butternut	7,236	5,292	1,944	-	-	-	45
Yellow poplar	-	-	-	-	-	-	-
Other hardwoods	350,109	106,922	53,035	28,146	12,601	149,405	46
Noncommercial spp.	2,271,991	41,995	21,749	612,114	310,120	1,286,013	50
Total	309,130,211	178,951,634	70,779,313	16,493,107	6,312,276	36,593,881	55
All species	410,800,315	238,927,152	87,285,258	20,135,995	7,519,691	56,932,219	52

(Table 19 continued on next page)

(Table 19 continued)

Western upper peninsula

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops and limbs	Bole	Tops and limbs		
	Green tons						Pounds
Softwoods							
Jack pine	3,592,943	2,728,717	523,413	61,924	11,387	267,502	46
Red pine	4,267,750	3,007,401	562,539	33,716	5,844	658,250	46
White pine	6,379,973	5,229,665	861,141	171,736	30,755	86,676	45
White spruce	11,864,567	8,038,980	2,854,921	119,473	40,952	810,241	45
Black spruce	7,297,454	3,419,831	1,445,107	40,317	17,512	2,374,687	45
Balsam fir	29,699,277	13,219,853	5,576,799	303,798	122,544	10,476,283	47
Hemlock	16,020,232	10,600,603	3,310,674	1,201,872	398,897	508,186	51
Tamarack	1,973,973	1,065,813	231,398	105,275	22,434	549,053	52
Eastern redcedar	4,344	3,282	1,062	-	-	-	43
Northern white-cedar	16,803,633	7,981,021	3,315,667	2,018,361	798,550	2,690,034	36
Other softwoods	39,975	9,351	3,732	-	-	26,892	44
Total	97,944,121	55,304,517	18,686,453	4,056,472	1,448,875	18,447,804	44
Hardwoods							
Select white oak	45,648	33,143	12,505	-	-	-	58
Other white oak	-	-	-	-	-	-	-
Select red oak	5,220,108	3,500,739	1,331,314	231,631	83,994	72,430	64
Other red oak	-	-	-	-	-	-	-
Select hickory	-	-	-	-	-	-	-
Other hickory	-	-	-	-	-	-	-
Basswood	10,334,451	6,421,689	2,630,748	529,821	210,794	541,399	42
Beech	18,624	5,534	1,871	7,334	2,814	1,071	59
Yellow birch	23,331,611	11,486,940	4,616,076	3,885,337	1,425,047	1,918,211	61
Hard maple	108,673,573	59,712,965	24,303,254	6,726,178	2,663,195	15,267,981	63
Soft maple	45,708,810	25,225,634	10,640,124	3,231,453	1,277,463	5,334,136	55
Elm	6,464,024	3,785,725	1,603,535	349,083	144,844	580,837	55
Black ash	6,816,740	3,225,329	1,492,350	240,351	110,109	1,748,601	50
White & green ash	2,062,867	1,247,189	509,346	71,561	28,741	206,030	51
Sycamore	-	-	-	-	-	-	-
Cottonwood	6,962	5,233	1,729	-	-	-	51
Willow	15,857	-	-	4,860	1,708	9,289	48
Hackberry	-	-	-	-	-	-	-
Balsam poplar	2,826,009	1,851,253	684,258	69,408	26,906	194,184	53
Bigtooth aspen	4,959,394	3,255,503	973,318	499,151	146,567	84,855	50
Quaking aspen	30,989,552	18,491,651	5,894,138	3,221,084	984,450	2,398,229	50
Paper birch	16,147,703	9,548,954	4,133,266	988,845	427,139	1,049,499	55
River birch	60,538	2,557	1,462	33,527	11,319	11,673	55
Black cherry	4,307,364	2,109,637	930,079	485,284	208,818	573,546	49
Black walnut	-	-	-	-	-	-	-
Butternut	-	-	-	-	-	-	-
Yellow poplar	-	-	-	-	-	-	-
Other hardwoods	18,178	2,532	981	10,343	4,322	-	46
Noncommercial spp.	2,685,058	44,273	22,294	670,272	341,153	1,607,066	50
Total	270,693,071	149,956,480	59,782,648	21,255,523	8,099,383	31,599,037	57
All species	368,637,192	205,260,997	78,469,101	25,311,995	9,548,258	50,046,841	53

(Table 19 continued on next page)

(Table 19 continued)

Eastern upper peninsula

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops and limbs	Bole	Tops and limbs		
	Green tons						Pounds
Softwoods							
Jack pine	6,809,641	4,715,075	956,935	253,101	50,622	833,908	46
Red pine	7,025,929	5,219,000	999,663	19,046	3,768	784,452	46
White pine	6,299,499	4,729,168	817,871	365,526	69,246	317,688	45
White spruce	6,980,035	4,790,248	1,726,857	59,337	21,326	382,267	45
Black spruce	9,730,855	4,028,090	1,736,853	62,958	25,666	3,877,288	45
Balsam fir	19,247,695	7,828,835	3,446,771	271,797	106,400	7,593,892	47
Hemlock	7,169,623	4,503,579	1,481,819	475,937	160,535	547,753	51
Tamarack	2,661,441	1,311,535	288,853	93,689	20,175	947,189	52
Eastern redcedar	-	-	-	-	-		
Northern white-cedar	32,521,798	12,985,858	5,972,894	2,383,946	1,041,445	10,137,655	36
Other softwoods	96,051	54,074	23,404	1,426	739	16,408	44
Total	98,542,567	50,165,462	17,451,920	3,986,763	1,499,922	25,438,500	42
Hardwoods							
Select white oak	26,822	11,871	4,893	4,141	1,864	4,053	58
Other white oak	-	-	-	-	-	-	-
Select red oak	1,480,130	953,405	377,562	101,349	41,453	6,361	64
Other red oak	-	-	-	-	-	-	-
Select hickory	-	-	-	-	-		-
Other hickory	-	-	-	-	-	-	
Basswood	2,211,950	1,407,381	574,193	104,371	40,231	85,774	42
Beech	11,328,746	5,996,064	2,318,315	1,619,140	608,717	786,510	59
Yellow birch	6,223,692	3,356,760	1,301,796	825,946	305,541	433,649	61
Hard maple	38,127,821	21,622,642	8,755,502	1,939,255	729,268	5,081,154	63
Soft maple	32,690,203	17,873,683	7,496,329	2,150,831	893,067	4,276,293	55
Elm	1,688,962	979,742	405,623	124,540	53,835	125,222	55
Black ash	4,895,082	1,721,441	847,886	238,430	118,449	1,968,876	50
White & green ash	1,394,841	870,409	366,476	59,318	24,711	73,927	51
Sycamore	-	-	-	-	-	-	-
Cottonwood	19,475	14,363	5,112	-	-		51
Willow	-	-	-	-	-		-
Hackberry	-	-	-	-	-	-	-
Balsam poplar	6,767,075	4,106,698	1,578,564	305,089	111,764	664,960	53
Bigtooth aspen	3,015,857	2,084,662	654,512	171,217	49,894	55,572	50
Quaking aspen	19,467,818	10,942,849	3,630,159	1,941,321	610,090	2,343,399	50
Paper birch	15,298,560	8,444,299	3,758,231	813,463	354,723	1,927,844	55
River birch	-	-	-	-	-		
Black cherry	3,729,754	1,599,741	681,994	590,207	266,582	591,230	49
Black walnut	-	-	-	-	-		
Butternut	-	-	-	-	-		
Yellow poplar	-	-	-	-	-		
Other hardwoods	4,772	3,159	1,201		-	412	46
Noncommercial spp.	908,157	6,271	2,958	230,628	116,839	551,461	50
Total	149,279,717	81,995,440	32,761,306	11,219,246	4,327,028	18,976,697	56
All species	247,822,284	132,160,902	50,213,226	15,206,009	5,826,950	44,415,197	49

(Table 19 continued on next page)

(Table 19 continued)

Southern lower peninsula

Species group	All components	Component					Average weight per cubic foot (including bark)
		Growing stock		Cull		1- to 5-inch trees	
		Bole	Tops and limbs	Bole	Tops and limbs		
	Green tons						Pounds
Softwoods							
Jack pine	594,448	392,143	77,409	-	-	124,896	46
Red pine	2,381,565	1,810,678	346,197	114,012	22,461	88,217	46
White pine	3,067,898	2,341,560	428,906	121,322	22,530	153,580	45
White spruce	364,408	105,765	46,853	7,927	2,666	201,197	45
Black spruce	-	-	-	-	-	-	-
Balsam fir	8,760	6,408	2,352	-	-	-	47
Hemlock	363,033	263,208	77,237	-	-	22,588	51
Tamarack	257,669	170,379	39,417	8,540	1,573	37,760	52
Eastern redcedar	137,681	15,418	6,215	-	-	116,048	43
Northern white-cedar	298,029	113,248	55,832	25,886	12,076	90,987	36
Other softwoods	1,980,815	841,807	357,430	149,103	61,837	570,638	44
Total	9,454,306	6,060,614	1,437,848	426,790	123,143	1,405,911	45
Hardwoods							
Select white oak	14,141,979	9,250,661	3,565,706	376,395	137,521	811,696	58
Other white oak	-	-	-	-	-	-	-
Select red oak	16,108,689	11,278,348	4,186,292	309,511	107,298	227,240	64
Other red oak	4,545,806	3,116,236	1,190,657	81,861	35,939	121,113	64
Select hickory	3,731,892	2,465,587	997,481	66,778	22,981	179,065	63
Other hickory	2,827,559	1,875,955	747,641	55,224	22,226	126,513	59
Basswood	4,002,850	2,494,274	941,630	180,550	68,567	317,829	42
Beech	2,468,748	1,585,349	560,437	194,831	75,710	52,421	59
Yellow birch	707,808	317,966	133,520	80,441	30,897	144,984	61
Hard maple	7,680,280	4,658,540	1,730,832	331,097	99,856	859,955	63
Soft maple	22,837,981	13,574,985	5,190,406	1,303,317	426,345	2,342,928	55
Elm	5,264,527	1,946,722	971,329	224,605	100,018	2,021,853	54
Black ash	2,252,529	1,052,749	495,030	64,961	31,677	608,112	50
White & green ash	12,561,137	7,293,583	2,979,816	347,041	128,687	1,812,010	51
Sycamore	641,406	475,534	148,514	13,869	3,489		58
Cottonwood	2,807,305	1,838,778	676,305	48,917	15,327	227,978	51
Willow	1,331,680	715,854	250,297	244,080	79,670	41,779	48
Hackberry	30,635	19,316	9,095	-	-	2,224	52
Balsam poplar	563,684	387,054	147,917	21,206	7,507		53
Bigtooth aspen	3,567,772	2,461,290	756,430	87,572	27,959	234,521	50
Quaking aspen	5,183,751	3,029,964	1,035,579	197,825	67,759	852,624	50
Paper birch	1,497,490	865,576	395,772	34,742	14,999	186,401	55
River birch	-	-	-	-	-	-	-
Black cherry	6,674,303	3,544,855	1,465,757	428,241	177,686	1,057,764	49
Black walnut	1,365,583	921,890	359,551	41,629	13,996	28,517	54
Butternut	305,539	163,190	71,837	16,206	5,484	48,822	45
Yellow poplar	710,737	474,730	177,884	-	-	58,123	52
Other hardwoods	3,205,549	1,076,116	502,039	232,922	106,212	1,288,260	46
Noncommercial spp.	3,281,667	69,205	31,952	524,784	259,966	2,395,760	50
Total	130,298,886	76,954,307	29,719,706	5,508,605	2,067,776	16,048,492	55
All species	139,753,192	83,014,921	31,157,554	5,935,395	2,190,919	17,454,403	54

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Smith, W. Brad; Hahn, Jerold T. Michigan's forest statistics, 1987: an inventory update. Gen. Tech. Rep. NC-112. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 44 p.

The Michigan 1987 inventory update, derived by using tree growth models, reports 17.3 million acres of timberland, a decline of less than 1 percent since 1980. Growing-stock removals have risen sharply since 1979, climbing from 275 million cubic feet annually to the current level of 398 cubic feet.

KEY WORDS: Forest area, timberland, forest inventory, land use, update.

1966-86



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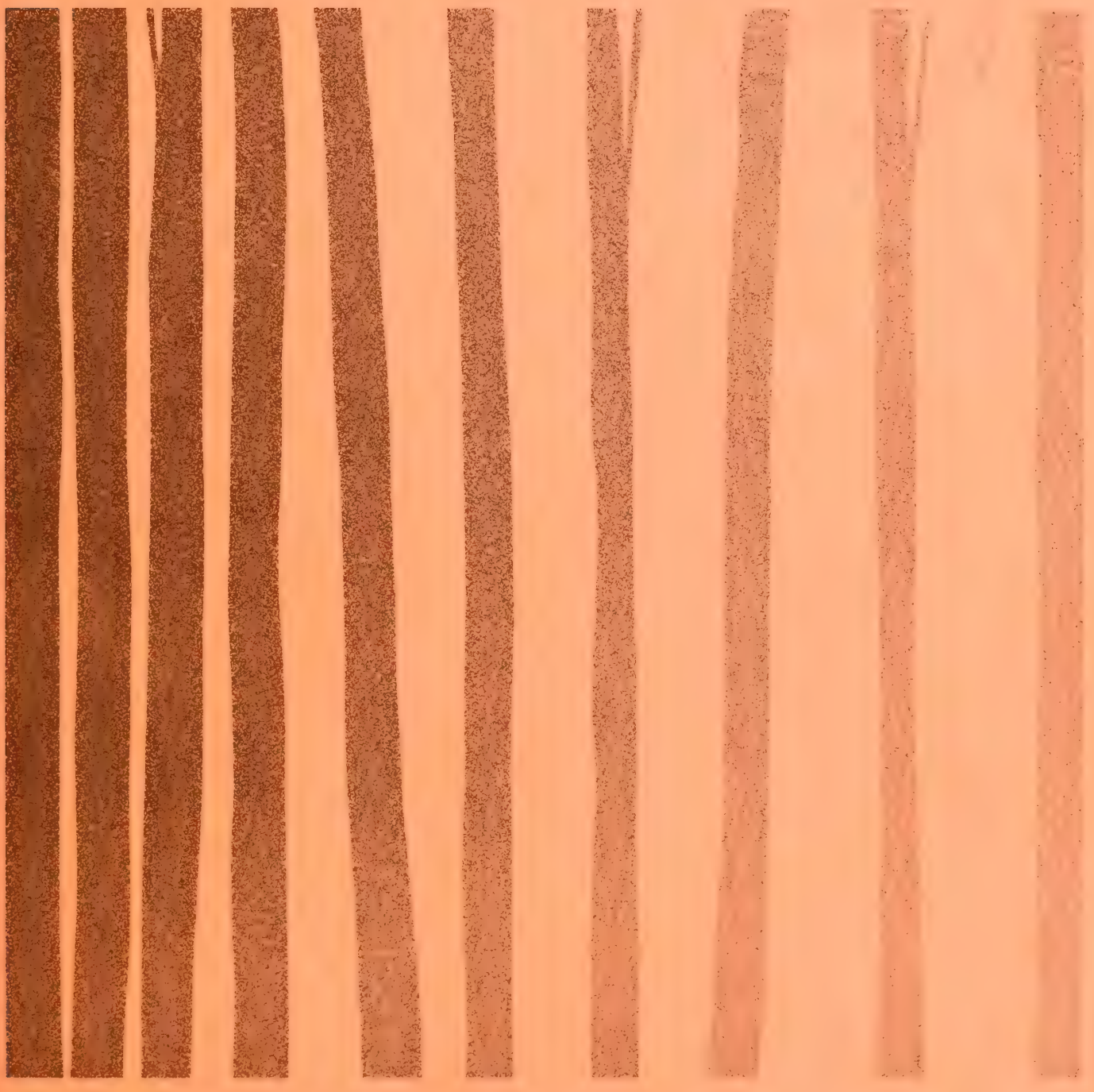
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General Technical Report **NC-113**

Hardwood Thinning Opportunities in the Lake States



Each contributor submitted camera copy and is responsible for the accuracy and style of his or her paper.

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HARDWOOD THINNING OPPORTUNITIES IN THE LAKE STATES

Proceedings of a Symposium

Escanaba, Michigan

April 20, 1984

John A. Sturos, Compiler

North Central Forest Experiment Station

USDA Forest Service

Houghton, Michigan

Sponsored by:

Department of Forestry, Michigan Technological University
North Central Forest Experiment Station, USDA Forest Service
Bay de Noc Community College
Michigan Association of Timbermen
Michigan-Wisconsin Timber Producers Association

PREFACE

This is an exciting time for forestry in the Lake States where we have an expanding resource base, particularly hardwoods, and are close to major markets. We have the industrial technology to produce the fiber and energy needed to meet market demands, and we have plenty of labor, due in part to reductions in other industries.

Major industrial expansions are taking place in the northern Lake States, the largest of which is the $500 million Champion International pulp mill at Quinnessec, Michigan. Several new waferboard plants have been built in Minnesota and Wisconsin; in Michigan, a new oriented strandboard plant has been built by Weyerhaeuser in Grayling, and Louisiana-Pacific has built a new medium density fiberboard plant in Newberry. In addition, large investments have been made or announced in hardwood lumber mills and other smaller wood products companies in northern Michigan. In total, the recent expansion in Michigan alone approximates $1 billion in capital investment and will create about 1,300 new jobs.

The primary fiber resource to supply these plants is the abundant hardwood stands. Northern hardwoods are the main "crop" on 10 million acres of forest land in the Lake States. Most of today's northern hardwoods are second-growth stands that grew after the clearcutting and high-grading that took place between 1900 and 1930. These stands are typically even-aged, composed of poles 5 to 9 inches in diameter, often poor in quality, slow growing, and in need of thinning.

The industrial expansion in the Lake States encourages us to more intensively manage our hardwood stands and allows us to get into intermediate operations such as hardwood thinning. Besides providing fiber for industrial consumption, these thinnings will enable us to accelerate the growth of high-quality crop trees. This will ensure that high-value veneer and sawlogs, the backbone of this hardwood region for many years, will continue to be available in the future.

Research on managing and utilizing northern hardwoods has been in progress for many years by public agencies, the universities of the region, and industry. Much information has been developed and is available for use by land managers. This symposium is one method of transferring the available technology to potential users; I hope that this is only a start in improving our technology transfer efforts. Also, I am sure that the dialogue that took place during this symposium will provide direction for future research.

We are pleased to cooperate with universities, trade associations, public and private landowners, and others in our research. We have been especially pleased to cooperate with Michigan Technological University, Bay de Noc Community College, the Michigan Association of Timbermen, and the Michigan-Wisconsin Timber Producers Association in co-sponsoring this symposium.

ROBERT A. HANN
Director
North Central Forest Experiment Station

CONTENTS

Page

Some Strategic Considerations in Managing Hardwood Forests in the Lake States
Dr. Henry H. Webster 1

The Lake States' Hardwood Resource
John S. Spencer, Jr. 6

Silvicultural Considerations in Thinning
Richard M. Godman 26

Harvesting Hardwood Thinnings
John A. Sturos and Michael A. Thompson 31

A 9-year Evaluation of Mechanized Thinning in Northern Hardwoods
Gayne G. Erdmann, James A. Mattson, and Robert R. Oberg 54

Evaluation of 1978 Thinning Site
James A. Johnson 69

Damage to the Residual Stand Resulting from Mechanized Thinning of Northern Hardwoods
Johann N. Bruhn 74

Impact of Harvesting to the Soil
C. C. Trettin and E. A. Padley 85

Hardwood Opportunities Utilizing the Pack-a-back System
Richard F. Bierlich 91

Logger's Perspective of Thinning Hardwoods
Marvin Roberts 93

Session II - Discussion 96

Economics of Thinning from the Forest Management Standpoint
Dr. Gerald J. Thiede 102

Existing and Future Products from Hardwood Thinnings
Edwin Kallio 108

Application of the System 6 Process to Hardwood Thinnings
Hugh W. Reynolds and Edwin Kallio 114

Session III - Discussion 120

Panel on Forest Management Prospectives: Hardwood Thinning Opportunities on National Forest Lands in the Lake States
Myron L. Smith 122

Large Industrial Forest Management Perspective of Hardwood Thinning
Ermine J. Venuto 124

Hardwood Opportunities on Wisconsin's State and County Forest
James E. Halvorson 127

Sawmill Industry Viewpoint
Richard Connor, Jr. 134

Research Needs for Hardwoods in the Lake States
David F. Karnosky 136

Converting Timber Stand Improvement Areas to Commercial Thinning in the Northeastern Area
Lloyd R. Casey 139

Timber Supply and Hardwood Thinning Opportunities on Michigan's Nonindustrial Private Forests
Eugene M. Carpenter 143

Summary of Hardwood Thinning Symposium
Craig Locey 149

Session IV - Discussion 151

SOME STRATEGIC CONSIDERATIONS IN MANAGING HARDWOOD FORESTS IN THE LAKE STATES

Dr. Henry H. Webster[1/]

Abstract.--Forest resources in our part of the country have recently taken on greatly increased importance for society. The hardwood component of forest resources seems to be taking on increased importance and potential. Carefully selected hardwood management practices pay off quite well. But three major questions at strategic level will require the most careful attention.

These are my major points. Each can be usefully, but modestly, expanded.

INTRODUCTION

It is my pleasure to take part in this important symposium. I will attempt to set the stage for your detailed discussions of hardwood thinning opportunities. My remarks quite frankly draw heavily on two earlier presentations, the first made at the 1982 SAF national convention in Cincinnati, the second made at the SAF regional technical conference held in Duluth during 1983. Several points made on those occasions are relevant here.

FOREST RESOURCES HAVE GREATLY INCREASED IMPORTANCE FOR SOCIETY

Forest resources were highly important in the original development of the Great Lakes region. They provided both raw material and financial capital for development of mid-continent United States. Their importance then declined significantly in a relative sense as other sectors of our economy and society expanded and prospered. Forest resources were then important primarily to the resources community itself. The dominant economy of the Great Lakes region (based in steel, heavy machinery, and automobiles) has recently undergone severe contraction as every casual newspaper reader is well aware. This effect is so serious that it is at the heart of political campaign arguments over industrial policy.

One notable result is a major effort to develop and diversify the regional economy. Major efforts are going forward in all of the Great Lakes states, with a substantial measure of interstate cooperation at several levels with overall leadership provided by the Great Lakes Governors Association. Forest resources and industries are an important part of these efforts. In Michigan, for example, there are just three target sectors at this point. Two involve renewable resources, namely forest resource and industries, and agricultural processing. The third is certain high-value parts of the automobile industries.

[1/]State Forester, Michigan Department of Natural Resources

Michigan's efforts to develop forest resources and industries are spearheaded by Governor Blanchard's 25-point initiative announced in this city last December 14. This initiative involves major proposals for improving the business climate for forest products industries, for assuring future timber supplies, for coordinating public and private forestry activities, and for creating innovative new arrangements (including funding) to carry these matters forward. Rather similar efforts are going forward in Wisconsin and Minnesota. And at the same time the nationally-known Conservation Foundation is carrying out an analysis of major regional forest policy issues. This analysis is intended to help positive timber-based development go forward with adequate attention to naturalistic and recreational values of forest resources.

These activities all illustrate one very simple point: Forest resources are again a major part of the fundamental social and economic agenda of this region. This simple fact places a premium on professionally competent, technically adequate, and socially sensitive management of forest resources. Our sessions here today help to lay part of a strengthened basis for such management.

HARDWOOD RESOURCES ARE EMERGING

Hardwoods have historically taken second place to softwoods in a considerable number of situations. Softwoods have been generally more useful due to a number of factors, particularly length of fibers and usefulness in construction. High-quality hardwoods used in furniture manufacture have been an exception to this overall pattern.

Breakthroughs in utilization and marketing of hardwoods have taken place to varying degrees several times in recent decades. We appear to be approaching what may in fact be a major breakthrough. Technologic developments and external economic forces seem to be converging toward this result.

Several technologic developments appear to be increasing the usefulness of a considerable number of hardwood species. These developments include the press-drying process for paper production, and the saw-dry-rip process for lumber production. In both cases, hardwoods and softwoods appear to be more nearly interchangeable than was previously the case. This is to the considerable relative advantage of hardwoods.

External economic forces relate especially to rising transportation costs, and their effect on alternative sources of timber products for the large market centers of the Great Lakes region. Our major cities have historically been supplied to major extent with paper and building products from the Deep South, eastern Canada, and the Pacific Northwest. Transportation costs have increased a great deal since this pattern was established. Energy costs affected by OPEC are the root of this. Production closer to market centers has become substantially more attractive as a result. Development of the various types of composite board industries in the Lake States has been substantially a result of this set of economic forces.

These developments and forces suggest that a major breakthrough concerning hardwoods may be occurring. This can be said even if we recognize that some apparent earlier breakthroughs only half to two-thirds happened.

In all of this there is an important central issue. How do we go about matching industrial processes and forest resources? To what degree do we change industrial processes to take advantage of kinds of timber that grow fairly naturally and easily? Or to what degree do we change forest resources to grow timber in greatest demand for today's industrial processes? What balance do we strike between these two different approaches? This is at the heart of questions concerning management of hardwoods versus conversion to softwoods. There is no single, simple, and universally applicable answer. But major efforts to more effectively use relatively abundant hardwood resources do appear to me to be a most important direction. This amounts to running to the wide side of the field in simple resource terms. In addition, industrial processes can be adapted more quickly than extensive areas of forests can be converted and brought to maturity.

"The wide side of the field" is an important concept. Our region currently has lower timber prices than other major forested regions of the United States. This is a result of less intense utilization than in the South and Pacific Northwest. These lower prices are now a positive attractant for timber industry development as timber supplies in these other U.S. regions, and in Canada, tighten up appreciably for a variety of reasons. We should take care not to lose this advantage immediately. Management must intensify. However, real effort is needed to focus on practices that are both economically efficient and compatible with continuing low cost of final product.

CAREFULLY SELECTED HARDWOOD MANAGEMENT PRACTICES PAY OFF QUITE WELL

We can now turn our attention to management practices designed to assure a stable supply of improved hardwood timber in the future.

The fact is that some such practices pay off quite handsomely in hardheaded financial terms if viewed as moderately long-term investments.

Pay off can be usefully measured via real rates of return for complete management regimes for particular forest types. Real rates of return are over and above inflation: they measure how rapidly investments in management practices "grow into" increased values at harvest. The effects of management in increasing volume, improving quality, and shortening time required to reach a given stand condition are all reflected in higher rates of return. If timber prices increase faster than prices for other goods and services this is also reflected. Real rate of return plus the overall inflation rate equals interest rate that can be compared with that offered at the bank or elsewhere. Management regimes for particular forest types assume that the most appropriate silvicultural practices for each type are applied in a technically correct manner in sequence at optimum times. It is further assumed that management is applied only on productive sites. These assumptions are powerful statements concerning the absolute need for technically skilled application of silvicultural practices.

Real rates of return in the range of 9 to 12 percent per year have been calculated in competently done analyses for several regional forest types. For example, such rates have been calculated for the northern hardwood type, and (in a more restricted sense) for good quality oaks on productive sites. Similarly, rates in this same range have been calculated for our principal pine

types. Rates of return for active timber management are markedly lower in the aspen type and in secondary softwood types such as spruce-fir. This difference in returns among types has a simple, elemental cause: aspen and spruce-fir grow about as well by themselves as they do with deliberate silvicultural effort. The other types are substantially more responsive.

Rates of return can also be calculated for individual practices. This has been done in a number of major analyses made over the past twenty-five years. Such calculations tend to show higher rates of return for intermediate practices than for regeneration; indeed they tend to show higher rates for intermediate practices (e.g. thinning) carried out relatively late in the rotation than for generally similar practices carried out earlier.

A part of these higher rates for late practices is spurious: the arithmetic mechanics of compound interest automatically raises rates of return for shorter-term as compared with longer-term investments. But there is a valid point with practical application in those forest types that regenerate fully and easily with little managerial attention, as do a number of hardwood types. Management regimes for these types can appropriately begin with thinning or other intermediate practices. Such regimes generally pay off at higher rates than do those for types where major regeneration efforts and expenditures are necessary.

THREE MAJOR FACTORS REQUIRE ATTENTION

These high rates of return give a promising picture for deliberate management of hardwood resources. Thinning is obviously an important part of such management.

Three matters of large scope require our most serious collective attention, however, if this promise is to be fulfilled. The first is the cost advantage to timber industries now provided by relatively low-cost timber in our region. From a developmental perspective it is important to prolong this advantage. Can we do so as management becomes more intensive? We probably can if we focus adequately. But this won't happen automatically. There is particular reason to worry about complex forms of management that can readily run up costs in relation to output. Traditional individual tree management of northern hardwoods, with thinning carried out by traditional means, is perhaps an outstanding example. Therefore it is particularly important to develop simplified management approaches for this type, as it is also important to develop efficient methods and machinery for carrying out specific practices such as thinning.

The second crucial question is the matter of investment. We must liberate ourselves from the idea that nothing can be invested in producing improved forests. Of course, it costs less in an immediate sense if thinning or other practices can be done on a wholly commercial basis. But to limit ourselves to that basis alone may mean continuing in a classic low-level trap. Past practices have given us somewhat ragged forests. If we limit ourselves to improvement that can be immediately financed from current receipts we are perpetuating this condition unnecessarily. The point of keeping costs down is not to avoid investment. Rather it is to invest in practices and situations

that give a lot of improved final result in relation to amount of investment. That is the point of the excellent rates of return cited earlier.

The third crucial question concerns expansion of market and utilization opportunities for hardwoods. We have already noted technologic developments and economic forces that are fostering such expansion. But this will not happen automatically. It will require sustained effort by many organizations both public and private. It will require sustained effort in basic research, in specific technologic development, in plant improvement, and in efforts to attract additional forest products firms to our region.

A united front is essential in these efforts. To my eye, the Lake States forest resources community is developing much greater cohesiveness than was ever previously the case, even though we still have some distance to go. And we have new allies who are interested in forest resources for their regional developmental potential. That is most encouraging.

THE LAKE STATES' HARDWOOD RESOURCE

John S. Spencer, Jr.[1/]

Abstract.--The Lake States contained 34.3 million acres of commercial forest land in 1977 in hardwood forest types--75 percent of the total commercial area. The aspen and maple-birch types with 12.9 and 10.9 million acres, respectively, lead all others. Thinning is the appropriate treatment, from a silvicultural viewpoint, for an estimated 3.0 million acres, half of which is in the maple-birch type.

"One hot day during the close of August, Margolis ran amok. He complained that perspiration kept running down his glasses, and although he could not see without them, he could not see with them either. Although it was intensely hot, Wagner ran the line through the hardwood lowland at full speed, trying to get away from the maddening insects. Margolis, inhaling small insects with every breath, ran into a springy cedar snag, which catapulted him through the air. He snorted like an infuriated bull when he got up and charged the snag with a wild burst of speed. The snag did not break, however, but threw him backwards into the brush again. This time he ran at it with his hand axe, exclaiming while he hacked, 'There, damn you, -- take that, and that! And when it came down, triumphantly, 'and THAT!'"

These words, written about 1937 by Harry G. Gafvert, member of the first Forest Survey team to inventory the timber resources of the Lake States, tell us something of the sense of purpose and direction instilled in those young men of long ago as they completed their precedent-setting survey. The words also tell us, perhaps, of an early application of thinning, the subject of this symposium. The rest of the paper portrays the hardwood resource as it exists presently in the Lake States.

OLD SURVEY METHODS

The survey Mr. Gafvert helped complete between 1933 and 1936 came about because of a public concern that the country might be running out of timber--an understandable fear given the Nation's insatiable appetite for timber and the general absence of applied forest management in the 19th and early 20th centuries. The legislative foundation for nationwide forest inventories was laid in 1928 with passage of the McSweeney-McNary Forest Research Act.

1/Principal Resource Analyst, North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minnesota.

Foresters used a system of sampling in the Lake States that was developed in Sweden. Cruise lines were run 10 miles apart in an east-west direction across the State. Crews measured 1/5-acre plots every 10 chains (660 feet) along these lines. Field work continued year-round, and in isolated areas the crews camped on the line to keep from dead-heading long distances back to a road at night. Working conditions were demanding in the mid-1930's, with the lack of good maps, down parkas and sleeping bags, lightweight camp gear, insulated boots, and even reliable insect repellent.

NEW SURVEY METHODS

A few things have changed since that first survey. We are now called Forest Inventory and Analysis rather than Forest Survey. Our primary legislative mandate now is the 1974 Forest and Rangeland Renewable Resources Planning Act, which broadened the scope of state-wide inventories. Sampling techniques changed also to combine information obtained from aerial photos with data measured on the ground -- commonly called a two-stage sampling technique. Field plots measured on the ground are a subsample of aerial photo points examined under a stereoscope. The field plots are a cluster of 10 points located 70 feet apart, covering an area of about one acre. The crew establishes a variable-radius plot at each of the 10 points. Field crews still work year-round, however, and they share many of the difficulties of their counterparts of the past. The data generated from every inventory is largely purchased by the sweat of these hard-working and unsung people.

LAKE STATES TIMBER RESOURCE

The inventory information that follows is dated 1977, but it comes from three surveys of different dates. The Michigan and Minnesota inventories are dated 1980 (Spencer 1983) and (Raile and Smith 1983) and 1977 (Jakes 1980) and (Spencer 1982), respectively. Fieldwork for the new inventory of Wisconsin was completed in January, 1984, and preliminary data are available for three of the five Forest Survey Units. However, statewide data are not complete. Therefore, data from the 1968 survey, which were computer-updated to 1977 for the National Assessment (USDA Forest Service 1982), are used here.

AREA

Forest land in the United States amounted to 736 million acres in 1977--one-third of the Nation's total land area (table 1). The Pacific Coast and South, with 29 and 28 percent of the total forest land, respectively, lead all other regions (fig. 1). The Lake States, with 5 percent of the Nation's land area, contain 7 percent of its forest land, 50 million acres.



Figure 1.--Regions of the United States.

Table 1.--Area of forest land by land class, and region, United States, 1977

(In million acres)

Region	Total forest land	Commercial forest land	Productive-reserved	Other forest land
Pacific Coast	214.3	70.6	4.1	139.6
South	206.9	188.0	2.1	16.8
Rocky Mountain	137.8	57.8	8.4	71.6
Northeast	83.1	77.4	3.8	1.9
Central	40.5	39.2	0.7	0.6
Prairie	3.1	2.6	--	0.5
Lake States	50.0	45.7	1.8	2.5
All Regions	735.7	481.3	20.9	233.5

Although the Pacific Coast Region contains the largest area of forest land, only one-third of it is commercial forest land. Nearly two-thirds is unproductive or deferred forest land--either incapable of producing crops of industrial wood because of adverse site conditions, or temporarily deferred from harvesting until studies under RARE II are completed to determine whether the land should be included in the wilderness system. The South, then, contains the largest area of commercial forest, 188.0 million acres. Ninety-one percent of the Lake States' forest land is commercial forest, 45.7 million acres. Productive-reserved forest accounts for 1.8 million acres and unproductive forest makes up the remaining 2.5 million acres.

Among the Lake States, Michigan leads in forest and commercial forest area (table 2). Minnesota leads in area of productive-reserved forest (primarily the Boundary Waters Canoe Area Wilderness and the Voyageurs National Park), and unproductive forest.

Table 2.--Area of forest land by land class, Lake States, 1977

(In million acres)

State	Total forest land	Commercial forest land	Productive-reserved	Other forest land
Michigan	18.4	17.5	0.6	0.3
Minnesota	16.7	13.7	1.2	1.8
Wisconsin	14.9	14.5	--	0.4
Lake States	50.0	45.7	1.8	2.5

Nationwide, commercial forest area has declined by 3.6 percent since 1952. The Northeast was the only region to show a gain, largely because of abandoned farmland reverting naturally to forest. The Lake States declined 10.6 percent, second only to the Prairie States' 13.9 percent drop:

Region	Change
Northeast	+ 6.0
South	(-)2.1
Pacific Coast	(-)5.4
Central	(-)6.0
Rocky Mountain	(-)9.6
Lake States	(-)10.6
Prairie	(-)13.9
All Regions	(-)3.6

Among the Lake States, Minnesota showed the biggest decline between 1952 and 1977, 2.9 million acres or 17.5 percent (table 3). Much of this was due to conversion of commercial forest land to productive-reserved forest.

Table 3.--Area of commercial forest land in the Lake States, 1952, 1962, 1970, and 1977

(In million acres)

Year	Total	Michigan	Minnesota	Wisconsin
1952	51.0	19.1	16.6	15.3
1962	49.2	19.1	15.4	14.7
1970	47.8	18.8	14.5	14.5
1977	45.7	17.5	13.7	14.5

Two forest types dominate Lake States timber stands, accounting for 56 percent of the commercial area--the aspen-birch type (32 percent) and the maple-birch type (24 percent) (table 4). The aspen-birch type has received increased attention, especially in Minnesota, since the advent of the wafer-board industry. The aspen-birch type is most extensive in Minnesota where it comprises 50 percent of the commercial forest. The maple-birch type is most widespread in Michigan, accounting for 35 percent of that State's commercial area.

Table 4.--Area of commercial forest land in the Lake States, by forest type, 1977

(In million acres)

Forest type	Total	Michigan	Minnesota	Wisconsin
White-red-jack pine	3.7	1.7	0.8	1.2
Spruce-fir	6.9	2.6	2.9	1.4
Oak-hickory	5.4	1.8	0.9	2.7
Elm-ash-cottonwood	3.1	1.3	0.7	1.1
Maple-birch	10.9	6.1	1.3	3.5
Aspen-birch	14.9	3.8	6.9	4.2
Nonstocked	0.8	0.2	0.2	0.4
All types	45.7	17.5	13.7	14.5

The proportion of area in each stand-size class reveals much about what has happened in the past to those stands. In the West where old-growth stands are common, two-thirds of the commercial area is in sawtimber stands (table 5). In the South where much of the forest is intensively managed, the commercial area is fairly evenly divided among the three stand-size classes. The Lake States is the only region where sawtimber stands do not predominate. This reflects the continuing maturation and rebuilding of stands from the cutover and burned over conditions prevalent in the late 19th and early 20th centuries.

Table 5.--Percent of commercial forest land in each stand-size class, United States, 1977

(In percent)

Region	Sawtimber	Poletimber	Sapling and seedling	Nonstocked
South	38	31	28	3
Northeast	40	29	29	2
Pacific Coast	66	14	14	6
Rocky Mountain	67	20	9	4
Central	42	27	28	3
Prairie	40	28	14	18
Lake States	25	47	27	1
All regions	45	28	24	3

Poletimber stands are somewhat more widespread in Minnesota, where they account for 51 percent of the area, than in Wisconsin (46 percent) or Michigan (45 percent) (table 6). The proportion of sawtimber stands is greater in Michigan (29 percent) than in Minnesota (23 percent) or Wisconsin (23 percent). The proportion of nonstocked commercial forest in the Lake States is lower than in any other region.

Table 6.--Area of commercial forest land in the Lake States, by stand-size class, 1977

(In million acres)

Stand-size class	Total	Michigan	Minnesota	Wisconsin
Sawtimber	11.5	5.1	3.1	3.3
Poletimber	21.4	7.8	7.0	6.6
Sapling and seedling	12.1	4.4	3.4	4.3
Nonstocked	0.7	0.2	0.2	0.3
All classes	45.7	17.5	13.7	14.5

The percent of area in hardwood forest types in the Lake States by stand-size class parallels the percent for all forest types (table 7). However, the proportions for individual forest types vary considerably. Sapling-seedling stands make up 36 percent of the aspen forest type and 27 percent of the elm-ash-cottonwood type, but only 18 percent or less of other hardwood types. Seventy-two percent of the paper birch type and 52 percent of the aspen type are in poletimber stands. Other hardwood types contain 43 percent or less of poletimber stands. Sawtimber stands are most prevalent in the oak-hickory and maple-birch types, with 41 and 40 percent, respectively.

Table 7.--Area of commercial forest land by hardwood forest type, stand-size class, and state, Lake States, 1977

(In thousand acres)

Forest type	All Lake States	Michigan	Minnesota	Wisconsin
Oak-hickory				
Sawtimber	2,165	684	453	1,028
Poletimber	2,189	782	361	1,046
Sapling and seedling	978	308	80	590
All stands	5,332	1,774	894	2,664
Elm-Ash-Cottonwood				
Sawtimber	993	453	195	345
Poletimber	1,358	471	389	498
Sapling and seedling	871	402	155	314
All stands	3,222	1,326	739	1,157
Maple-birch				
Sawtimber	4,410	2,480	675	1,255
Poletimber	4,662	2,568	494	1,600
Sapling and seedling	1,832	1,050	115	667
All stands	10,904	6,098	1,284	3,522
Aspen				
Sawtimber	1,580	534	907	139
Poletimber	6,724	1,505	3,281	1,938
Sapling and seedling	4,619	1,368	1,663	1,588
All stands	12,923	3,407	5,851	3,665
Paper birch				
Sawtimber	197	35	142	20
Poletimber	1,393	270	758	365
Sapling and seedling	337	70	97	170
All stands	1,927	375	997	555
All hardwood types				
Sawtimber	9,345	4,186	2,372	2,787
Poletimber	16,326	5,596	5,283	5,447
Sapling and seedling	8,637	3,198	2,110	3,329
All stands	34,308	12,980	9,765	11,563

Fifty-six percent of the area of hardwood forest types grows stands that are aged 50 years or younger, and 70 percent of them grows stands 60 years of age and younger (table 8). The longer-lived oak-hickory and maple-birch types contain smaller proportions in the younger age classes--only 56 percent of both types is in stands less than 60 years old. This compares with 90 percent of the aspen type and 78 percent of the paper birch type, both composed of shorter-lived species.

Table 8.--Area of commercial forest land by hardwood forest type and stand-age class, Lake States, 1977

(In thousand acres)

Stand-age class (years)	All types	Oak-hickory	Elm-ash-cottonwood	Maple-birch	Aspen	Paper birch
1-10	3,789	459	332	716	2,167	115
11-20	3,178	328	296	651	1,759	144
21-30	2,164	171	242	455	1,178	118
31-40	4,442	528	308	906	2,423	277
41-50	5,736	744	333	1,731	2,486	442
51-60	4,865	738	416	1,678	1,619	414
61-70	2,801	581	347	996	662	215
71-80	1,937	477	247	795	317	101
81-90	1,636	428	232	758	160	58
91-100	1,318	332	169	706	87	24
101-120	1,522	394	191	870	55	12
121+	920	152	109	642	10	7
All ages	34,308	5,332	3,222	10,904	12,923	1,927

Site index indicates the quality of a site in terms of the height of a free-growing tree at age 50 of a representative species of the forest type. Among hardwood forest types in the Lake States the weighted average site index is 62.4 feet. Michigan is highest with 65.2 feet. Wisconsin and Minnesota follow with 60.8 and 60.4 feet, respectively.

Highest average site indices are in the aspen type (65.8 feet) and the maple-birch type (63.1 feet), followed by the paper birch type (58.4), the elm-ash-cottonwood type (57.4 feet), and the oak-hickory type (57.1 feet). Considering all hardwood types together, 43 percent of the commercial forest area grows stands whose site index is 60 feet and shorter, and 72 percent of the area grows stands whose site index is 70 feet or less (table 9).

Table 9.--Area of commercial forest land by hardwood forest type and site-index class, Lake States, 1977

(In thousand acres)

Site-index class (feet)	All types	Oak-hickory	Elm-ash-cottonwood	Maple-birch	Aspen	Paper birch
11-20	1	--	--	--	1	--
21-30	92	16	31	22	17	6
31-40	1,332	425	378	236	206	87
41-50	4,427	1,260	672	1,194	1,024	277
51-60	8,870	1,570	887	2,932	2,780	701
61-70	10,145	1,191	630	3,575	4,121	628
71-80	6,436	603	326	2,062	3,255	190
81-90	2,410	211	168	698	1,296	37
91+	595	56	130	185	223	1
All classes	34,308	5,332	3,222	10,904	12,923	1,927

The weighted average basal area of growing-stock trees at least 5 inches d.b.h. in hardwood forest types in the Lake States is 79.8 square feet per acre. Stands are somewhat more dense in Michigan, averaging 84.7 square feet, followed by Minnesota (79.0 square feet) and Wisconsin (74.8 square feet). The maple-birch type contains the densest stands, averaging 93.2 square feet per acre (table 10) -- 95.4 square feet is the average in Michigan, 90.7 in Wisconsin, and 90.3 in Minnesota. The paper birch type is second in average basal area of its stands with 81.7 square feet per acre, followed by the oak-hickory type (77.9 square feet), the elm-ash-cottonwood type (75.5 square feet), and the aspen type (69.9 square feet).

Table 10.--Area of commercial forest land by hardwood forest type and basal-area class of growing-stock trees, Lake States, 1977

(In thousand acres)

Basal-area class (sq.ft.per acre)	All types	Oak-hickory	Elm-ash-cottonwood	Maple-birch	Aspen	Paper birch
0-20	2,071	224	233	299	1,223	92
21-40	3,358	360	437	567	1,801	193
41-60	5,633	1,003	557	1,076	2,713	284
61-80	6,292	1,239	591	1,766	2,347	349
81-100	6,156	1,160	479	2,239	1,895	383
101-120	5,185	830	420	2,242	1,407	286
121-140	3,690	389	323	1,801	938	239
141+	1,923	127	182	914	599	101
All classes	34,308	5,332	3,222	10,904	12,923	1,927

Since 1952 the Nation's volume of growing stock has increased 18 percent during the same time the area of commercial forest land declined by almost 4 percent. The Pacific Coast is the only Region where the growing-stock volume declined during the 25-year period. Pacific Coast volume dropped 11 percent during the period as old growth timber continued to be liquidated. Growing-stock volume in the Lake States increased 76 percent between 1952 and 1977--faster than any other region. Softwood volume rose from 6.7 to 12.3 billion cubic feet during the period, a gain of 84 percent, while hardwood volume increased from 18.3 to 31.8 billion cubic feet, a gain of 74 percent (table 11).

Table 11.--Volume of growing stock on commercial forest land by region, year, and softwoods and hardwoods, United States, 1952, 1962, 1970, and 1977

(In billion cubic feet)

Year and species group	Pacific Coast	South	Rocky Mtn.	Northeast	Central	Prairie	Lake States
1952							
Softwoods	251.6	58.2	87.5	20.0	0.9	--	6.7
Hardwoods	12.6	78.2	4.0	43.2	21.1	1.1	18.3
All species	264.2	136.4	91.5	63.2	22.0	1.1	25.0
1962							
Softwoods	241.8	71.6	93.1	24.0	1.1	0.1	9.1
Hardwoods	14.9	84.5	4.5	52.8	24.6	1.1	24.5
All species	256.7	156.1	97.6	76.8	25.7	1.2	33.6
1970							
Softwoods	230.8	84.9	94.4	27.9	1.3	0.1	10.4
Hardwoods	17.6	91.9	4.9	60.3	26.3	1.2	28.5
All species	248.4	176.8	99.3	88.2	27.6	1.3	38.9
1977							
Softwoods	219.1	97.1	94.9	31.0	1.6	0.1	12.3
Hardwoods	16.9	104.9	4.9	67.3	27.7	1.3	31.8
All species	236.0	202.0	99.8	98.3	29.3	1.4	44.1

Among the Lake States, growing-stock volume increased the fastest in Michigan where it gained 91 percent between 1952 and 1977 (table 12). Softwood volume increased substantially faster than hardwood volume in Michigan and Wisconsin. In Minnesota the reverse is true.

Table 12.--Volume of growing stock on commercial forest land by softwoods and hardwoods, Lake States, 1952, 1962, 1970 and 1977

(In billion cubic feet)

Year and species group	Total	Michigan	Minnesota	Wisconsin
1952				
Softwoods	6.7	2.4	2.7	1.6
Hardwoods	18.3	7.6	4.3	6.4
All species	25.0	10.0	7.0	8.0
1962				
Softwoods	9.1	3.6	3.4	2.1
Hardwoods	24.5	10.7	6.1	7.7
All species	33.6	14.3	9.5	9.8
1970				
Softwoods	10.4	4.3	3.4	2.7
Hardwoods	28.5	12.2	7.2	9.1
All species	38.9	16.5	10.6	11.8
1977				
Softwoods	12.3	5.4	3.5	3.4
Hardwoods	31.8	13.7	8.0	10.1
All species	44.1	19.1	11.5	13.5

Two-thirds of the Nation's softwood volume is found in the West (table 13). Another one-fifth is in the South. The Lake States Region contributes a meager 3 percent of the softwood volume, but this proportion has grown from 2 percent in 1952. The bulk of hardwood volume in the U.S. is in the South (41 percent) and the Northeast (26 percent). The Lake States Region grows a respectable 12 percent of the hardwood volume, up from 10 percent in 1952.

Table 13.--Volume of growing stock on commercial forest land by region and softwoods and hardwoods, United States, 1977

(In billion cubic feet)

Region	Total	Softwoods	Hardwoods
Pacific Coast	236.0	219.1	16.9
South	202.0	97.1	104.9
Rocky Mountain	99.8	94.9	4.9
Northeast	98.3	31.0	67.3
Central	29.3	1.6	27.7
Prairie	1.4	0.1	1.3
Lake States	44.1	12.3	31.8
All Regions	710.9	456.1	254.8

Michigan leads the Lake States in growing-stock volume with 43 percent of the total (table 14). Michigan's volume increased faster between 1952 and 1977 (91 percent) than Wisconsin (69 percent) or Minnesota (64 percent).

Table 14.--Volume of growing stock on commercial forest land, by state and softwoods and hardwoods, Lake States, 1977

(In billion cubic feet)

State	Total	Softwoods	Hardwoods
Michigan	19.1	5.4	13.7
Wisconsin	13.5	3.4	10.1
Minnesota	11.5	3.5	8.0
Lake States	44.1	12.3	31.8

The aspens (*Populus tremuloides* and *P. grandidentata*) are the dominant species group in the Lake States in terms of growing-stock volume with 8.2 billion cubic feet, more than twice as much as the 3.8 billion cubic feet of hard maple (*Acer saccharum* and *A. nigrum*), its closest competitor (table 15). Aspen was considered a weed species for years after it became widely established following intensive cutting of softwood and subsequent slash burning and wildfires. But now it is regarded as a highly valuable resource by the paper and waferboard industries and as vital food and cover for ruffed grouse, deer, and other wildlife species.

Table 15.--Volume of growing stock on commercial forest land by major species and state, Lake States, 1977

(In billion cubic feet)

Species	Total	Michigan	Minnesota	Wisconsin
Aspen	8.2	2.6	3.4	2.2
Hard maple	3.8	2.7	0.2	0.9
Soft maple	3.0	2.3	0.1	0.6
Paper birch	2.8	0.8	1.3	0.7
Select red oak	2.8	1.2	0.6	1.0
Balsam fir	2.1	0.8	0.9	0.4
Northern white-cedar	2.0	1.3	0.4	0.3
Ash	1.7	0.7	0.5	0.5
Basswood	1.7	0.7	0.4	0.6
Jack pine	1.6	0.6	0.6	0.4

Increasing volumes per acre nationally explain how growing-stock volumes can climb at the same time commercial forest area is declining. In 1952 the U.S. average volume per acre was 1,208 cubic feet, but in 1977 it was 1,477, a 22 percent jump.

The differences in volumes per acre among regions reflect differences in stand-size class areas and average tree size. Commercial forests in the Pacific Coast Region, which are predominantly sawtimber stands, average 3,346 cubic feet per acre, almost twice as high as the next region. The Lake States, where poletimber stands predominate, average 964 cubic feet per acre, considerably lower than the national average:

Region	Growing-stock volume per acre 1977
	(Cubic feet)
Pacific Coast	3,346
Rocky Mountain	1,728
Northeast	1,270
South	1,074
Central	748
Prairie	544
Lake States	964
All Regions	1,477

Volumes per acre also vary widely by ownership class. Nationwide, the National Forests have the highest average growing-stock volume per acre, reflecting conditions in the West where most of the National Forests are found. In the Lake States, forest industry-owned land boasts the highest average volumes per acre, suggesting that these tracts were of higher than average site quality when they were acquired and that they have received good management. Other public-owned forests in the Lake States have the lowest average volume per acre, reflecting, among other things, the poor condition of much tax-forfeited land that came into county, municipal, or state ownership years ago:

Ownership Class	Growing-stock volume per acre 1977	
	United States	Lake States
	(Cubic feet)	
National Forest	2,575	1,116
Other public	1,606	851
Forest industry	1,545	1,186
Farmer and misc. private	1,082	954
All owners	1,477	964

Farmers and miscellaneous private parties own 51 percent of the growing-stock volume in the Lake States (table 16), just as they own 51 percent of the commercial forest area. Other public owners account for 25 percent, National Forests for 14 percent, and forest industry for 10 percent.

Table 16.--Volume of growing stock on commerical forest land by ownership class, Lake States, 1977

(In billion cubic feet)

Ownership class	Total	Michigan	Minnesota	Wisconsin
National Forest	6.1	2.8	1.9	1.4
Other public	11.0	3.8	4.5	2.7
Forest industry	4.6	2.4	0.6	1.6
Farmer and misc. private	22.4	10.1	4.5	7.8
All owners	44.1	19.1	11.5	13.5

GROWTH AND REMOVALS

Nationwide, the total volume of growth and removals has increased since 1952. Net annual growth of growing stock in the U.S. gained 56 percent during the period, and timber removals increased 20 percent. In 1976 the volume of removals was 66 percent of the volume of growth. The ratio of removals to growth is much higher for softwoods (82 percent) than it is for hardwoods (45 percent).

In the Lake States, growth and removals volumes have increased since 1952 also. Growth increased 37 percent and removals gained 44 percent between 1952 and 1976. The 1976 removals volume was 46 percent of growth, compared to 66 percent nationally. The softwood ratio of removals to growth is only 36 percent compared to 82 percent nationally. The hardwood ratio is 51 percent compared to 45 percent nationally.

The highest ratio of removals to growth in the Lake States is in Minnesota with 55 percent (table 17).

Table 17.--Net annual growth and removals by softwoods and hardwoods, Lake States, 1976

(In million cubic feet)

State	All species		Softwoods		Hardwoods	
	Growth	Removals	Growth	Removals	Growth	Removals
Michigan	678	274	206	56	472	218
Wisconsin	556	268	146	44	410	224
Minnesota	349	194	120	69	229	125
Lake States	1,583	736	472	169	1,111	567

Comparisons of growth and removals can lead to erroneous conclusions in areas such as the Lake States where stands are young and growth includes a substantial volume in trees too small to be a significant part of the removals volume. A more meaningful comparison is one between removals and the yields from land managed under cutting prescriptions representing expected or average future conditions. Such comparisons are not available for all the Lake States yet, but the one for Minnesota suggests that removals could be substantially higher.

Growth rates (growth as a percent of inventory) in the United States have increased since 1952, especially for softwoods. In spite of rising volumes of growth, growth rates in the Lake States have declined since 1952 as shown in the following tabulation. This situation is not unusual in states with young stands in which the inventory has been increasing rapidly. In such cases growth volumes cannot keep pace with inventory volumes, and growth rates drop.

Region and species group	Growth rate	
	1952	1976
	(Percent)	
United States:		
Softwoods	1.8	2.7
Hardwoods	3.5	3.7
Total	2.3	3.1
Lake States:		
Softwoods	4.6	3.8
Hardwoods	4.7	3.5
Total	4.7	3.6

The largest share of timber removals from growing stock in the U.S. was harvested as saw logs, and the next highest share was pulpwood. The proportions of these two products are reversed in the Lake States, as shown in the following tabulation:

Product	United States	Lake States
	(Percent)	
Saw logs	45	25
Pulpwood	24	43
Veneer logs and bolts	9	1
Fuelwood	2	3
Misc. indus. prod.	2	4
Logging residues	10	5
Other removals	8	19
Total	100	100

Seventy-seven percent of the 1976 Lake States' timber removals from growing stock was composed of hardwood species (table 18). Hardwoods, primarily aspen, accounted for 65 percent of the pulpwood harvested in the region. Wisconsin produced the largest proportion of pulpwood of all species (38 percent), as well as the largest share of hardwood pulpwood (42 percent). Eighty-four percent of all saw logs harvested were hardwoods, much of it aspen and hard maple. Half of all the saw logs harvested were from Michigan.

Table 18.--Timber removals from growing stock by item and softwoods and hardwoods, Lake States, 1976

(In million cubic feet)

Item	All species	Softwoods	Hardwoods
Pulpwood	313.9	108.4	205.5
Saw logs	183.4	28.9	154.5
Misc. indus. prod.	26.9	6.8	20.1
Fuelwood	24.8	0.6	24.2
Veneer logs and bolts	9.9	1/	9.9
Logging residues	34.9	4.4	30.5
Other removals	141.9	20.0	121.9
Total	735.7	169.1	566.6

1/Less than 50 thousand cubic feet.

THINNING AREA ESTIMATED

The North Central Station recently estimated the area of commercial forest that would benefit from various kinds of treatment for each of the 11 states in its region, as part of a national effort. Criteria for determining treatment class were based on Forest Inventory and Analysis data normally collected in the field. The criteria used were patterned as closely as possible after those used in the Forest Industries Council's Forest Productivity Project (Minnesota, Wisconsin and Michigan Forest Productivity Reports 1979). Each of the 11 states was treated the same way. Variables used to determine whether thinning was an appropriate treatment included forest type, site index, stand age and basal area. For example, stands were targeted for thinning in the maple-birch type whose site index was at least 55 feet, were 90 years or less in age, and whose basal area was 110 to 140 square feet per acre. A different range of these variables was applied for each forest type.

Other treatment classes included regeneration without site preparation, regeneration with site preparation, type conversion, intermediate cut, shelterwood cut, partial cut, salvage cut, cull tree removal, and no treatment.

Our study showed that thinning is the appropriate treatment, from a silvicultural viewpoint, on 3.0 million acres of hardwood types in the Lake States (table 19), 9 percent of the commercial area of hardwood types. The maple-birch type accounts for the largest area, 49 percent of the thinning total. Seventy percent of all sapling and seedling stands targeted for thinning are in the aspen type, and 60 percent of all poletimber stands for which thinning is a potential treatment is in the maple-birch type.

Table 19.--Area of commercial forest land in thinning treatment class by hardwood forest type, and stand-size class, Lake States, 1977

(In thousand acres)

Forest type and stand-size class	Lake States	Michigan	Minnesota	Wisconsin
Oak-hickory				
Poletimber	658	231	93	334
Sapling and seedling	27	4	-	23
Total	685	235	93	357
Elm-ash-cottonwood				
Poletimber	196	57	58	81
Sapling and seedling	55	32	5	18
Total	251	89	63	99
Maple-birch				
Poletimber	1,301	764	90	447
Sapling and seedling	140	91	1	48
Total	1,441	855	91	495
Aspen				
Poletimber	20	3	11	6
Sapling and seedling	550	223	87	240
Total	570	226	98	246
Paper birch				
Poletimber	-	-	-	-
Sapling and seedling	15	6	2	7
Total	15	6	2	7
All hardwood types				
Poletimber	2,175	1,055	252	868
Sapling and seedling	787	356	95	336
Total	2,962	1,411	347	1,204

Fifty-eight percent of the area of hardwood types targeted for thinning is in stands whose site class, a measure of productivity based on the volume of annual growth per acre produced by fully-stocked natural stands, is 50-85 cubic feet (table 20). Another 21 percent of it grows less than 50 cubic feet per acre annually. If economic constraints were applied, many of these stands would not be considered viable thinning opportunities.

Table 20.--Area of commercial forest land in thinning treatment class by hardwood forest type and site class, Lake States, 1977

(In thousand acres)

Forest type and site class (cubic feet of growth per acre per year)	Lake States	Michigan	Minnesota	Wisconsin
Oak-hickory				
120-165	-	-	-	-
85-120	113	58	10	45
50-85	443	175	77	191
Less than 50	129	2	6	121
All classes	685	235	93	357
Elm-ash-cottonwood				
120-165	-	-	-	-
85-120	11	4	1	6
50-85	34	17	5	12
Less than 50	206	68	57	81
All classes	251	89	63	99
Maple-birch				
120-165	24	22	-	2
85-120	251	141	14	96
50-85	902	543	41	318
Less than 50	264	149	36	79
All classes	1,441	855	91	495
Aspen				
120-165	11	5	4	2
85-120	202	92	25	85
50-85	341	121	66	154
Less than 50	16	8	3	5
All classes	570	226	98	246
Paper birch				
120-165	-	-	-	-
85-120	-	-	-	-
50-85	9	4	-	5
Less than 50	6	2	2	2
All classes	15	6	2	7
All hardwood types				
120-165	35	27	4	4
85-120	577	295	50	232
50-85	1,730	861	188	681
Less than 50	620	228	105	287
All classes	2,962	1,411	347	1,204

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SILVICULTURAL CONSIDERATIONS IN THINNING

Richard M. Godman[1]

Abstract.--For producing sustained yields of high-value northern hardwood veneer and sawlogs on medium and better sites in the Lake States, the author recommends uneven-aged management for tolerant sugar maple and even-aged management for less tolerant species such as basswood, white ash, yellow birch, and northern red oak. Suggestions for improving growth and quality development include: (1) selecting the best uniformly spaced crop trees to leave and release on the basis of crown size and stem form; (2) early thinning of sprout clumps down to the single best stem; (3) maintaining proper stand density by following recommended stocking level guides; (4) taking stand variation into account when marking; (5) thinning at regular 10-to 12-year intervals; and (6) using even-aged density levels for the first two thinnings in second-growth stand even if uneven-aged management is to be practiced later.

During this meeting we will review thinning in naturally established stands. This thinning phase of stand treatment is only part of the application of a silvicultural system. Over the last decade we have developed a better understanding of management methods and of the silvicultural systems that can be used in our northern hardwood stands. Treatments making up a silvicultural system include reproduction cuttings to establish a stand of preferred species followed by a series of intermediate cuttings to develop the stand for desired products and then to reproduction cuttings again. It seems easier to understand the choice and use of a silvicultural system if stand management is recognized as either even-aged or uneven-aged management. The pros and cons of the system that can be used for management methods are becoming clearer, and we know what can be done and what can be expected from various combinations of stand treatments.

As a quick review of some of the more recent changes regarding northern hardwood management, we recognize that simply applying a given silviculture system will not automatically produce the results that we want. We have to tailor stand treatments to the silvical characteristics of the species; one example is knowing the frequency of seed crops for the various species. Another example is providing seedbed conditions that give optimum germination temperatures. Optimum germination temperatures are not known for all our species. Recently we have found that northern red oak germinates at low temperatures just like sugar maple--under the snow. In our shelterwoods we also try to correlate shade levels that will hold back competition while stimulating seedling growth.

A number of factors that influence tree quality are: the role of forks and fork correction; how merchantable log height can be increased; controlling

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epicormic branching; crown closure; conditions that result in winter survival; and others, just to name a few.

Some of the major points we have learned about stand management that will assure us of having good quality stands can be summarized as follows:

1. Different species have different regeneration requirements.

2. The composition of the stand determines the proper stand density.

3. The individual tree, as well as the surrounding competition, tends to control its quality development.

4. Stand, as well as tree quality, must be developed through proper thinning schedules.

5. Species preference or composition determines whether even-aged or uneven-aged management is preferred. Either system can be used with sugar maple, but less tolerant species are mostly even-aged species; special shelterwood overstory and understory treatments are required to establish them.

6. Some successful regeneration methods reported for the Northeast and Canada do not work in the Lake States, and differences also exist within the Lake States region itself. For example, strip thinning on the Upper Peninsula Experimental Forest in Upper Michigan works well for regenerating yellow birch as long as there is a good birch seed supply, and advanced regeneration has been eliminated. Similar trials on the Argonne Experimental Forest failed miserably because of droughty conditions in July and August. We had birch regeneration, but we lost it to drought and competition with grass and raspberry plants.

The silviculture of established stands is simpler than the silviculture required to regenerate a new stand. Most of the young hardwood stands have developed following heavy cutting about 40 to 80 years ago. They tend to be even-aged, even-sized, and predominantly sugar maple. Occasionally some mixtures of white ash and basswood along with other species are present. The composition that we see today on the ground was established reproduction at the time the mature overstory trees were harvested, so what you see as advanced regeneration in the understory is normally what you get in the new stand, unless something is done to change the situation at regeneration time. We think that the best silviculture for these stands is to maintain proper thinning density. Initial thinning in second-growth stands will usually develop best under even-aged stocking levels. This was a big change in our thinking. The past recommendation was to leave a residual stand containing 85 square feet of basal area (Arbogast 1957). Currently, we recommend using the minimum stocking levels from figure 6 in the Northern Hardwoods Manager's Handbook (Tubbs 1977) for the first thinning in 5- to 9-inch dbh pole-size stands to bring them under even- or uneven-aged management. These cuts are heavy enough to get good responses and operable cuts. We have cut these pole-size stands down to 60 square feet of basal area by releasing crop trees and removing over half of the original stand basal area or cubic-foot volume, but the cut is primarily from below and leaves

a uniform stand of the best dominant and codominant trees. The next operable thinning will be made after about 20 years and to the average stocking level shown in the Northern Hardwoods Manager's Handbook (Tubbs 1977). Remember that the proper thinning density changes with average stand diameter. Therefore, in theory, no two stands are really ever marked the same because no two stands ever have the same average stand diameter.

If the stand has more basswood or hemlock, figures 7 and 8 of the Manager's Handbook recommend leaving higher residual basal areas for a given stand diameter. The reasoning for this is that the crown sizes of basswood and hemlock are much smaller for a given diameter than they are for sugar maple, white ash, and other wide-crown species. Thinning operations in higher residual density hemlock stands, overmature hemlock-yellow birch stands, and old-growth northern hardwoods stands should not remove more than 40 percent of the original stand basal area (Jensen 1943) or more than 40 percent of the gross volume (Gilbert and Jensen 1958). The reasons for these recommendations are that hemlock and yellow birch are very sensitive to sudden exposure following heavy cutting and that post-logging decadence in overmature stands is reduced by lighter thinnings in overmature stands. In thrifty hemlock-hardwood stands, light partial cuttings that remove less than one-third of the stand have been suggested for maintaining a productive stand (Eyre and Zillgitt 1953). Initial thinning treatments can often be heavier in smaller and younger stands than in larger and older stands, but for yellow birch it has been suggested that no more than 40 percent of the basal area be removed at one time (Godman and Marquis 1969).

One important overriding principle in thinning is the uniformity of stocking left in the residual stand. Uniformity enhances stem quality development as well as growth rate. Differences in stem quality are also related to site quality and species composition. In the Lake States, site quality for sugar maple ranges only from about site index 40 to 70 at age 50. On a given sugar maple site, site index for faster growing basswood and ash is usually 10 to 15 feet higher. The best stem quality occurs on site indices greater than 60. Stand quality in northern hardwoods is always enhanced when straight, long, clean-boled basswood and ash stems occur in mixtures with sugar maple, red maple, yellow birch, and other northern hardwood species.

Tree quality has to be continually developed due to forking in most northern hardwood species. All sugar maple trees in the overstory fork because of the frequent loss of the terminal bud. Maintaining proper density and crown closure next to forks are the most important in controlling forking. These factors correct the lower forks and result in greater merchantable log heights. Stem form and natural pruning are generally good in basswood and ash but relatively slow in developing in the maples and yellow birch. Proper crown size is the main factor that controls epicormic branching following thinning. In unthinned stands all crowns tend to be reduced, and their size must be gradually increased to inhibit epicormic sprouting. Crown release and shelterwood studies have shown that fully crowned dominant and codominant trees can be fully released without the risk of lowering bole quality.

When marking young stands, the best trees should be selected following crop tree guidelines. It is necessary to follow this practice in successive thinnings as quality must be constantly developed. After four thinnings, most

residual trees have been developed into good quality stems, but some poor quality trees are still present.

In early thinnings, all undesirable or defective trees cannot be removed in a single cut--again, proper density should be maintained even if it means leaving some of these poorer trees. One NEVER rule, especially in two-storied stands, is that residual basal area per acre should never be less than 50 square feet. This rule prevents creation of large openings that usually result in quality loss on bordering trees.

Thinning of sprout clumps should be done in the earliest cuts. Recent findings indicate that thinning to the single best low-union stem is preferred. This applies to all the sprouting species. Another thing to remember is, if stumps are cut low, only low sprouts will be produced.

Thinning frequency is extremely important in developing quality as well as maintaining growth and salvaging mortality. Our results show that growth in stands thinned to prescribed levels starts to drop between the tenth and fifteenth year. In other studies, irregular thinning intervals resulted in minimal quality improvement as compared to trees that were not selected as potential crop trees. In general, it appears that periodic thinnings give the best results when they are done at regular 10- to 12-year intervals.

It should be emphasized that by using even-aged guidelines for the initial and second thinnings, the growth and early quality development are improved and stand structure will begin to emerge, even though the stand is to be managed later as uneven-aged. The main reason is that proper density during the early thinnings is lower than the 85 square feet that was previously recommended for uneven-aged management (Arbogast 1957).

In conclusion, the best silviculture in thinning is to:

1. Consistently maintain the proper stand density--when in doubt, leave stocking slightly heavier than the guides to maximize quality development.

2. Select to leave individual trees, within the stocking level guide, on the basis of crown size and stem form.

3. NEVER cut below 50 square feet in stands 5 inches dbh and larger, even if it means leaving an undesirable tree.

4. Recognize stand variation when marking.

5. Thin sprout clumps early and heavily.

6. Maintain periodic thinnings at regular 10- to 12-year intervals.

7. Use even-aged density levels for the first two thinnings even if the stand will be managed uneven-aged later.

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HARVESTING HARDWOOD THINNINGS

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Abstract.--Five case studies of thinning hardwoods were done on gentle and difficult terrain (slopes up to 50 percent) using both fully mechanized and semimechanized systems. Tracked and rubber-tired feller/bunchers were evaluated in conducting several thinning patterns. Grapple skidders, forwarders, and a combination of a radio-controlled winch and forwarder were used to transport whole trees, tree-length logs, or shortwood to roadside. Slashers processed the tree-length material into pulpwood and fuelwood; whole-tree chippers produced fiber and fuel chips. Information is presented on the harvesting operations, equipment costs, and productivity. Typical yields ranged from 50 to 75 tons/acre of whole-tree chips.

INTRODUCTION

The growth in population and associated economic and industrial activity in the United States has caused the projected demand for hardwoods to increase from 3.0 billion cubic feet in 1976 to 9.6 billion cubic feet in 2030 (Hair 1980). Although the U.S. grows more hardwoods than ever before, use has been limited because of timber quality and availability problems. Most of our pole-size northern hardwood forests are in deplorable condition and in dire need of thinning--stands are characterized by far too many small and low-quality trees per acre. The result is overutilization of high-quality, preferred hardwoods and underutilization of small and low-quality hardwoods.

The magnitude of the problem is realized when one considers that there are an estimated 32 million acres of northern hardwood forests in the eastern United States, a large portion of which are occupied by overstocked poletimber stands. To meet the projected demand for hardwoods, acceptable methods of thinning must evolve to improve the growth and quality of the residual trees. Only by removing the smaller, poorly formed trees and undesirable species will the growth of higher quality, larger trees and preferred species be encouraged.

Little documentation is available in the Lake States on the cost and productivity of logging equipment to thin hardwoods. Loggers well realize that a machine may work profitably in one stand but not in another. Information on cost and productivity of logging equipment and systems over a wide range of conditions is essential to develop profitable and silviculturally attractive solutions to mechanical thinning. Economic factors such as high interest rates, sharp increases in fuel cost and other operating costs, along with the marketing

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problem for small-size forest products, emphasize the need to search for ways to make logging operations more cost-effective and productive. Damage to the site and residual stand must also be considered. We need to determine the relative numbers and kinds of wounds generated by mechanized thinning operations and the circumstances under which they occur. From this information, guidelines can be developed for timber sale planning and marking that will minimize the impact of harvesting equipment on residual stocking.

To advance the state of the art of thinning hardwoods, we need to conduct a number of case studies under a variety of conditions and approaches to thinning. This paper summarizes five case studies in northern Michigan and Wisconsin from 1974 to 1982.

CASE I - 1974 MECHANIZED THINNING

This study was initiated to determine the cost and productivity of a mechanized system to thin pole-size northern hardwoods under four harvesting strategies (Biltonen et al. 1976, Arola and Miyata 1981). The study area was a 50-acre block divided into 5-acre compartments. The soil was sandy loam, and the topography was essentially flat. The stand contained 13 cords of hardwood pulpwood per acre and about 2,700 board feet of sawtimber per acre. The basal area was about 100 square feet per acre in trees 6 inches diameter at breast height (dbh) and larger. The stand contained 350 trees per acre (all sizes) and had an average dbh of 6 inches with a dbh range of 2 to 28 inches. Red maple was the dominant species (55 percent), followed by sugar maple (25 percent), and other species (20 percent).

Equipment and Manpower

The mechanized system used consisted of a John Deere[2] 544 loader fitted with an accumulating Rome grapple shear, a Clark 667 grapple skidder, a Trelan D-60 whole-tree chipper, a loader to feed the chipper, a maintenance truck, a fuel truck, a chain saw, two truck/tractor units, four chip vans, and a landing tractor. Seven people--four equipment operators, a supervisor, and two truck drivers--were required for the operation.

Productivity and Cost

The total production of the system was 1,829 tons over 106 scheduled hours (SH) or an average of 17 tons per SH. The average productivity and the average cost of extracting this material (excluding stumpage, road building, and miscellaneous overhead costs) are given by equipment type in table 1. The overall average for all thinning treatments was $11.34 per green ton. (All dollar amounts in this paper are 1983 dollars.) Hauling was the major component of this cost (37 percent).

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[2]The use of trade, firm, or corporation names is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.

Table 1.--Average productivity and cost per ton[a] by equipment type - Case I.

Equipment type	Stems/PH[b]	Stems/SH[b]	Tons/PH	Tons/SH	Cost[c] per ton (dollars)	Percent of total cost
John Deere 544 feller/buncher	133.3	88.8	27.2	17.5	2.00	18
Clark 667 grapple skidder	135.0	72.5	31.3	16.8	2.42	21
Trelan D-60 whole-tree chipper	172.3	82.2	34.8	17.2	1.97	17
Two road tractors					3.05	27
Four chip vans					0.38	3
Landing tractor					0.75	7
Maintenance truck					0.70	6
Fuel truck					0.07	1
TOTAL					11.34	100

[a]Average of all thinning treatments.
[b]PH = productive hour; SH = scheduled hour.
[c]Based on a labor cost of $10/SH.

CASE II - 1978 STRIP-WITH-SELECTION THINNING

The objective of this study was to further evaluate the economic and silvicultural benefits of using a mechanized harvesting system to thin northern hardwood pole-size stands under the strip-with-selection system (Johnson et al. 1979). This thinning system was concluded to be the most favorable in an earlier study (Biltonen et al. 1976). The study area consisted primarily of sugar maple (73 percent) and American elm (22 percent). The initial stocking was 254 trees per acre, resulting in 116 square feet of basal area per acre.

Equipment and Manpower

The harvesting system used in the operation consisted of a Drott 40LC feller/buncher, a John Deere 740 grapple skidder, a Morbark 22-inch whole-tree chipper, five truck/tractor units, five chip vans, a maintenance truck, and a fuel truck. The crew consisted of three equipment operators and five truck drivers.

The Harvest

The scope of the study was limited to the production of 1,000 tons of green chips from the thinned area for a contract with a local utility company for a trial whole-tree chip burning experiment. This limited the total area thinned to 13 acres that was harvested using the strip-selection thinning pattern. The selectively thinned area between the strips was thinned to a basal area of about 68 square feet per acre. The average yield was 78.1 green tons per acre--much higher than the 46.8 green tons per acre obtained in the 1974 thinning study (Case I). The higher yield was due to the fact that the timber sale required the removal of all elm trees due to Dutch elm disease.

Productivity and Cost

The total production of 1,000 green tons of whole-tree chips by the mechanized whole-tree harvesting system was accomplished in a period of 33 SH. This gave a productive rate of 30.3 tons per SH. The Drott 40LC feller/buncher averaged 94.0 stems per productive hour (PH) or 71.7 stems per SH. The potential felling and bunching productivity was not met due to a malfunctioning accumulator arm on the feller/buncher; therefore, the feller/buncher averaged only 1.3 stems per cycle.

Skidding productivity was increased by keeping skid distances short. The average skid distance was 321 feet in the woods and 72 feet on the access road that permitted one skidder to feed the chipper. The skidder averaged 11.4 stems per cycle or 4.2 tons per cycle. With an average cycle time of 5.1 minutes, the productivity of the skidder was 49.4 tons per PH.

The chipping rate was 41.5 green tons per PH. Each van load required an average of 6.0 skidder loads or 68.6 stems. Chipper productivity was hampered by limited chip van availability. Rain created poor road conditions which interfered with trucking efficiency.

The machine rates and estimated costs for harvesting this material (excluding stumpage, road building, and miscellaneous overhead costs) are given by machine in table 2. The total cost per green ton was $11.08 of which hauling represented 40 percent.

Table 2.--Scheduled hours (SH), productive hours (PH), machine rates, and cost per ton by equipment type - Case II.

Equipment type	Observed Time		Machine Rate		Cost[a] per ton (dollars)	Percent of total cost
	SH	PH	Fixed ($/SH)	Operating ($/PH)		
Drott 40-LC feller/buncher	39	29.10	23.37	18.80	1.85	17
John Deere 740A grapple skidder	33	20.20	25.71	27.50	1.73	16
Morbark 22-inch Chiparvestor	33	24.10	32.19	39.20	2.34	21
Five road tractors	165	2,080 mi[b]	8.56	0.49/mi	4.08	37
Five chip vans	165	2,080 mi[b]	1.25	0.05/mi	0.31	3
Maintenance truck	33	-	1.69	0.34/SH	0.40	3
Fuel truck	33	-	0.77	0.43/SH	0.37	3
TOTAL					11.08	100

[a]Based on a total system production of 1,000 tons and labor cost of $10/SH.
[b]Total distance traveled by trucks and vans was 2,080 miles (52 miles round trip, 25 tons/van).

CASE III - 1981 MECHANICAL SELECTIVE THINNING

The objective of this study was to determine the productivity and cost of mechanical selective thinning using three different feller/bunchers followed by grapple skidding and slashing. The study area was 21 acres of pole-size mixed hardwoods on the Watersmeet Ranger District of the Ottawa National Forest, Section 35, T45N, R38W. The soil was a moderately well drained sandy loam, and the topography ranged from level to 10-percent slopes.

The area was divided into three blocks ranging from 6.5 to 7.8 acres. The timber was mixed hardwoods with trees up to 24-inch dbh. Point sample cruises of each block resulted in the following species compositions and basal areas before thinning:

	Block A	Block B	Block C
	(percent)		
Sugar maple	67	62	81
Aspen	5	1	-
Elm	5	16	8
Red maple	13	2	1
Yellow birch	1	7	-
Basswood	2	6	6
Miscellaneous	7	6	4
TOTAL	100	100	100
Basal area (sq. ft./acre)	124	139	148

Operations and Equipment

All hardwoods, except aspen, had been marked for a selective thinning before cutting. All aspen, balsam fir, spruce, hemlock, and cedar were to be removed even though they were not marked. Before cutting, the stand was marked to yield basal areas of "cut" and "leave" trees within each block according to the following tabulation.

	Block A	Block B	Block C
	(sq. ft. per acre)		
"Cut" trees	37.5	43.5	35.4
"Leave" trees	86.6	95.6	113.1
Total Basal Area	124.1	139.1	148.5

Cut trees included both sawtimber (over 11 inches dbh) and pole-size trees (5 to 11 inches dbh). Pole-size trees were cut by the three feller/bunchers; sawtimber was cut by chain saw. In Block A, a Melroe Bobcat Model 1075 feller/buncher with a 16-inch shear was used. In Block B, the poletimber was felled and bunched with a Timbco Hydro-Buncher Model 2518 with an 18-inch shear mounted on a knuckle boom. In Block C, an Omark Hydro-Ax Model 311 feller/buncher with a 16-inch shear was used.

All pole trees were stacked on the ground in skidder-size bunches. They were then topped at a 5-inch diameter, and the merchantable boles were limbed by chain saw. The tree-length material was then skidded by a Garret Tree Farmer C5D grapple skidder to a landing for slashing into 100-inch pulpwood bolts by a truck-mounted Hood pulpwood slasher.

Sawtimber trees were felled and bucked into sawlogs and pulp bolts to a minimum diameter of 5 inches by a chain saw operator at the stump. Following bucking, the logs and bolts were either skidded with a John Deere 440 cable skidder or the grapple skidder to a roadside landing. Based on the basal area of only the cut trees in each block, the average tree diameters at breast height for blocks A, B, and C were 10.6, 10.4, and 9.3 inches, respectively.

The slasher wood from the small trees and the pulpwood bolts from the tops of the sawtimber trees were hauled 12 miles to a pulpwood yard where each load was weighed and the net weight obtained. Each truck load had been measured for average height and length and the number of stacked cords computed. Sawtimber bolts (100 inches long) were loaded and trucked 24 miles to a sawmill. For convenience of reporting, we converted sawlog board foot values to cords at the rate of 2 cords per 1,000 board feet, although the standard unit of measurement for sawlog bolts is board-foot volume. Time study and productivity data were taken on each phase of the harvest and transport operation.

Results

Volumes removed from each block were summarized into three product categories: sawtimber bolts; pulpwood from the tops of sawtimber trees; and pulpwood from poletimber (table 3).

Table 3.--Volumes removed from the three harvested blocks - Case III.

	Block A	Block B	Block C	Total
Sawtimber (board feet)	4,410	7,900	9,540	21,850
Pulpwood from topwood (cords)	9.47	19.68	20.64	49.79
Pulpwood from poletimber (cords)	13.05	17.53	31.55	62.13

The amount of material harvested in each block differed considerably. In Block A, 4,410 board feet of sawtimber and 22 cords of pulpwood were harvested; in Block C, 9,540 board feet of sawtimber and 52 cords of pulpwood were harvested. These differences stem from the variations in the blocks in stand composition, basal area, and other conditions. Block C obviously contained a much better stand of timber; therefore it is not appropriate to compare the productivity and harvesting costs of the three feller/bunchers.

Because the logger's cost data were not available, independent cost analyses were made that required certain assumptions. The economic life assumed for

the various pieces of equipment ranged from 1 year for the chain saws to 3 years for the skidders to 5 years for the feller/bunchers. We assumed all the equipment were scheduled to work 2,000 hours per year. The percent utilization assumed for the equipment ranged from 50 percent for the chain saws to 65 percent for the feller/bunchers to 67 percent for the skidders. The PH per year were obtained by multiplying the SH (2,000) by the percent utilization (table 4). The fixed and operating machine rates are also listed in table 4.

Table 4.--Equipment hourly machine rates - Case III.

Equipment	PH/year	Machine rates	
		Fixed	Operating
		($/PH)	
Melroe Bobcat	1,300	14.09	9.00
Timbco Hydro-Buncher	1,300	33.02	16.64
Hydro-Ax feller/buncher	1,300	16.87	10.40
Garret Tree Farmer grapple skidder	1,340	21.69	14.29
John Deere cable skidder	1,340	14.22	9.73
Pioneer chain saw (Model 440C)	1,000	0.63	1.75
Sachs-Dolmar chain saw (Model 114)	1,000	0.43	1.59
Stihl chain saw (Model AV Super)	1,000	0.53	1.68
International truck	1,200	10.48 (.31/mi)	17.64 (.53/mi)
Prentice loader	1,200	4.78	9.84
Slasher and truck	1,300	11.16	8.32

The productivity and cost of producing pulpwood from the poletimber in the three blocks by the mechanized thinning system are of primary interest (tables 5 and 6). The productivity of the three feller/bunchers ranged from 3.4 to 4.7 cords per PH that resulted in a felling and bunching cost range of $7.76 to $15.52 per cord. This difference is most likely due to a difference in stand conditions between the three blocks. The skidding productivity and costs were quite constant over the three cutting blocks, ranging from 3.1 to 3.2 cords per PH and $12.68 to $14.38 per cord. The slashing productivity and costs ranged from 7.7 to 9.1 cords per PH, giving a cost range of $4.61 to $5.61 per cord. The overall cost to produce slashed wood decked at roadside (excluding trucking costs) ranged from $27.18 to $37.17 per cord. By including the costs to haul the slashed wood 12 miles to a pulpwood yard, the total cost ranged from $31.47 to $41.52. According to data in a recent Timber Mart-North, the average price at the mill for hardwood pulpwood is $41.00 per cord, and the stumpage for mixed hardwoods is $4.00 per cord. This indicates that producing pulpwood from hardwood poletimber thinnings is a marginal operation.

The existence of sawtimber (trees larger than 11 inches dbh) in the stand obviously improves the economics. In this case study, the costs to harvest sawlogs and pulpwood from sawtimber trees ranged from $16.30 to $24.52 per cord (table 7). Assuming the same selling and stumpage values (even though the sawlogs would average $10.00 to $20.00 per cord more), approximately $15.00 to $21.00 per cord were realized from which overhead and other related costs must be deducted.

Table 5.--Productivity of each phase of the harvesting operation on the three blocks based on scheduled and productive hours - Case III.

Machine	Cords/SH	Cords/PH
Block A		
Slasher wood:		
Melroe Bobcat	2.81	3.36
Chain saw top and limb	4.90	7.59
Grapple skidder	2.43	3.25
Slasher	3.25	9.06
Sawlogs and topwood:		
Chain saw fell and buck	2.04	3.40
Cable skidder	1.86	2.53
Block B		
Slasher wood:		
Timbco	3.28	3.79
Chain saw top and limb	3.88	8.59
Skidders	2.59	3.20
Slasher	2.57	7.83
Sawlogs and topwood:		
Chain saw fell and buck	2.08	3.51
Skidders	2.08	2.65
Block C		
Slasher wood:		
Hydro-Ax	4.06	4.71
Chain saw top and limb	6.78	14.36
Skidders	2.42	3.14
Slasher	4.86	7.73
Sawlogs and topwood:		
Chain saw fell and buck	3.34	5.56
Skidders	3.29	4.39

Table 6.--Cost analyses of producing pulpwood from the poletimber for the three blocks - Case III.

Machine	Operation	SH	PH	Total cost (dollars)	Cost/cord (dollars/ cord)
	Block A (6.46 acres, 13.05 cords)				
Melroe Bobcat	Fell and bunch	4.64	3.88	126.39	9.68
Chain saw	Top and limb	2.66	1.72	24.91	1.91
Garret Tree Farmer grapple skidder	Skid	5.38	4.02	187.68	14.38
Slasher	Slash	4.01	1.44	60.13	4.61
Truck	Haul			57.26	4.39
TOTAL					34.97
	Block B (6.84 acres, 17.53 cords)				
Timbco	Fell and bunch	5.34	4.62	272.15	15.52
Chain saw	Top and limb	4.52	2.04	40.57	2.31
Garret Tree Farmer grapple skidder	Skid	5.85	4.59	211.95	12.09
John Deere cable skidder	Skid	0.92	0.89	28.68	1.64
Slasher	Slash	6.83	2.24	98.28	5.61
Truck	Haul			76.32	4.35
TOTAL					41.52
	Block C (7.76 acres, 31.55 cords)				
Hydro-Ax	Fell and bunch	7.77	6.70	244.87	7.76
Chain saw	Top and limb	4.65	2.20	41.85	1.33
Garret Tree Farmer grapple skidder	Skid	6.47	4.65	219.07	6.94
John Deere cable skidder	Skid	6.59	5.36	181.09	5.74
Slasher	Slash	6.49	4.08	170.80	5.41
Truck	Haul			135.46	4.29
TOTAL					31.47

Table 7.--Cost analyses of producing sawlogs and pulpwood from tops of sawtimber trees - Case III.

Machine	Operation	SH	PH	Total cost (dollars)	Cost/cord (dollars/ cord)
	Block A (6.46 acres, 18.29 cords)				
Chain saw	Fell and buck	8.96	5.38	96.77	5.29
John Deere cable skidder	Skid	9.84	7.24	252.12	13.78
Truck	Haul			99.76	5.45
TOTAL					24.52
	Block B (6.84 acres, 35.48 cords)				
Chain saw	Fell and buck	17.07	10.11	160.62	4.53
John Deere cable skidder	Skid	9.80	8.09	272.16	7.67
Clark cable skidder	Skid	7.22	5.30	198.53	5.60
Truck	Haul			179.46	5.06
TOTAL					22.86
	Block C (7.76 acres, 39.72 cords)				
Chain saw	Fell and buck	11.89	7.14	112.11	2.82
John Deere cable skidder	Skid	10.93	8.00	279.04	7.03
Clark cable skidder	Skid	1.14	1.05	37.01	0.93
Truck	Haul			219.34	5.52
TOTAL					16.30

CASE IV - 1982 RED OAK THINNING

The objective of this case study was to evaluate three levels of mechanization for thinning red oak poletimber by the strip-selection method. The study area was a portion of a 100-acre red oak poletimber stand owned and administered by Washburn County, Wisconsin, and managed by the Wisconsin Department of Natural Resources. The gently rolling tract is located about 5 miles southeast of Spooner, Wisconsin, in Sections 11 and 14 of T38N, R12W. The stand consists of a mixture of northern red oak pole and small sawtimber trees plus some aspen pulpwood and sawlog trees with a merchantable basal area of 150 square feet per acre. The 100-acre tract was marked for a strip-with-selection thinning by Wisconsin DNR personnel. The goal was to reduce the basal area of the residual stand to about 80 square feet per acre while producing firewood and aspen pulpwood.

Operations and Equipment

Three separate plots were designated within the stand to obtain data on the cost and productivity of thinning hardwoods using three different harvesting techniques ranging from a labor-intensive operation to a mechanized system. The equipment and procedures used in each operation are as follows:

Mechanized system:

- Timberjack Timbco Hydro-Buncher Model 2518 felled and bunched the trees operating from marked strips (fig. 1).
- Trees were manually topped and delimbed.
- Tree-length logs were skidded to the landing with a John Deere 640 grapple skidder (fig. 2).
- Self-propelled Hood slasher produced firewood and aspen pulpwood (fig. 3).

Semimechanized system:

- Trees were manually felled, delimbed, and topped.
- Tree-length logs were winched to marked strips by the Radio Horse, a radio-controlled winch, where the winch operator bucked them into shortwood (fig. 4).
- Shortwood was forwarded to the landing with a Gafner Iron Mule Model 4501F (fig. 5).

Labor-intensive system:

- Trees were manually felled, delimbed, bucked, and piled at the stump with a two-man team (sawyer and helper).
- Shortwood was forwarded to the landing with a Gafner Iron Mule Model 4501F.

Results

General information on the three portions of the stand harvested by the three different logging operations is presented in table 8. Although all three thinnings took place on similar plots, there was some difference in the amount of wood removed and the basal area remaining.

Table 8.--General data on the three plots harvested by the different systems - Case IV.

	Labor-intensive	Semi-mechanized	Mechanized
Area (acres)	1.75	2.80	5.8
Plot length (feet)	380	700	1,000
Plot width (feet)	250	200	750
Basal area after thinning (sq. ft./acre) (trees >5 inches)	65	78	68
Average diameter (inches)			
Before thinning	6	6	6
Trees removed	6	8	7
Products removed (cords)			
Hardwood	24.8	46.8	86.5
Aspen	12.0	4.3	21.2
Cords/acre	21.0	18.2	18.6

The mechanized harvesting system consisted of four operations. The trees were felled and bunched with a feller/buncher; they were then delimbed and topped manually with a chain saw. The bunches of tree-length stems were then skidded to the landing by a grapple skidder on the strips made by the feller/buncher, and finally the tree-length logs were mechanically bucked by a slasher that sorted and decked the material into firewood and aspen pulpwood.

Following a strip-selection felling pattern, the Timbco feller/buncher averaged 130 trees per PH that resulted in 12.7 cords per PH. The full productivity of the feller/buncher was not achieved because the accumulator was not operational. Based on a fixed machine cost of $23.30 per SH, an operating machine cost of $19.81 per PH, a labor cost of $10 per SH, and a production of 107.7 cords, the felling phase was estimated to cost $4.30 per cord (table 9).

The productivity of the chain saw operator, including a helper, in delimbing and topping the bunched trees was 118 trees per PH or 12.8 cords per PH. The average time needed to top and delimb each stem was 0.44 minutes. Some stems were missed due to the bunched trees, but this did not seem to affect the subsequent skidding and slashing operations. The estimated cost of this phase of the operation was $1.98 per cord (table 9).

Grapple skidding with the John Deere 640 averaged 87 trees per PH or 8.7 cords per PH. The average skid distance was 980 feet, round trip. The skidder

averaged 8.4 trips per hour (a little over 7 minutes per trip), hauling a payload of about nine trees or 0.9 cords per load. He averaged a travel speed of 340 feet per minute (4 mph). The feller had collected an average of 5.4 trees into each bunch it made; the skidder combined these bunches into payloads of about nine trees. The estimated cost of skidding was $6.14 per cord (table 9).

Table 9.--Machine rate and cost for each harvesting phase of the mechanized system - Case IV.

Equipment type	Observed time		Machine rate		Total labor cost[a] ($)	Total cost[b] ($)	Cost per cord[c] ($/cord	Percent of total cost
	SH	PH	Fixed ($/SH)	Operating ($/PH)				
Timbco 2518 feller/buncher	8.88	8.45	23.30	19.81	88.80	463.09	4.30	17
Chain saw for delimbing and topping	9.80	8.39	0.70[d]	1.29[d]	196.00[e]	213.68	1.98	8
John Deere 640 grapple skidder	14.22	12.19	18.74	20.74	142.20	661.50	6.14	25
Hood slasher	12.03	10.69	14.95	13.01	120.30	439.23	4.08	17
SUBTOTAL					547.30	1,777.50	16.50	
Shortwood truck	28.00	700 mi[f]	8.12	0.53/mi	280.00	878.36	8.16	33
TOTAL					827.30	2,655.86	24.66	100

[a]Labor cost is $10/SH.
[b]Total cost = labor cost + fixed cost + operating cost.
Total cost = labor rate x SH + fixed machine rate x SH + operating rate x PH = $10/SH x 8.88 SH + $23.30/SH x 8.88 SH + $19.81/SH x 8.45 PH = $463.09.
[c]Based on total system production of 107.7 cords from 5.8 acres.
[d]Two chain saws incurred fixed costs, and one incurred operating costs.
[e]This was a two-man operation with one sawyer and one helper who piled and removed slash. Therefore, total labor cost is $196.00 ($10/SH x 9.80 SH x 2).
[f]Total distance traveled was 700 miles (50-mile round trip with 8 cords per truckload).

Slashing was the final phase of the mechanized system with a productivity of 88 trees per PH or 10.1 cords per hour. The slasher had a self-loading grapple that picked up 3.4 trees per grapple load. During each cycle (load, slash, and unload), 6.5 trees were processed, producing 30.7 sticks. A total of 4,323 sticks was produced at 0.17 minutes per stick. This amounts to about 4.5 sticks per tree and a process time of 0.7 minutes per tree. The estimated cost of slashing was $4.08 per cord.

The trucking cost was estimated to be $8.16 per cord (table 9). It is based on a 25-mile haul (50-mile round trip) to a local firewood market. The total cost excluding stumpage and overhead was $24.66 per cord, of which trucking represented 33 percent and skidding 25 percent.

The semimechanized system was a three-man operation. One man did the felling, delimbing, and topping; the second man set up the radio-controlled winch, winched the tree-length logs to the marked strip road, bucked the logs into 100-inch sticks, and did a minor amount of piling; and the third man operated the forwarder.

For the study, 2.8 acres were thinned using this logging system. The area was long and narrow, about 200 feet by 700 feet, with a skid road down the center of the plot. Felling and winching were conducted as a "hot" operation and began on the outer edges and progressed toward the skid road. This procedure minimized winching through slash. The sawyer felled, delimbed, and topped 16 trees per PH or 2.0 cords per PH. Based on a total production of 51.1 cords and a labor cost of $10.00 per SH, the estimated cost of felling, delimbing, and topping was $8.65 per cord (table 10).

Table 10.--Machine rate and cost for each harvesting phase of the semimechanized system - Case IV.

Equipment type	Observed time		Machine rate		Total labor cost[b]	Total cost	Cost per cord[c]	Percent of total cost
	SH	PH	Fixed ($/SH)	Operating ($/PH)	($)	($)	($/cord)	
Chain saw	38.19	25.79	0.70[a]	1.29[a]	381.90	441.90	8.65	26
Radio Horse winch	37.87	25.72	1.54	1.75	378.70	482.03	9.43	28
Gafner 4501F forwarder	13.83	13.06	7.82	8.19	138.30	353.41	6.92	21
SUBTOTAL					898.90	1,277.34	25.00	
Shortwood truck[d]						416.98	8.16	25
TOTAL						1,694.32	33.16	100

[a]Two chain saws incurred fixed costs; one incurred operating costs.
[b]Labor cost is $10/SH.
[c]Based on total system production of 51.1 cords from 2.8 acres.
[d]The same trucking costs are assumed as in the mechanized system - Table 9.

The winch operator also averaged 2.0 cords per PH that included not only winching, but also bucking and a minor amount of piling. Seven winch locations were used, and, on the average, the snatch block was set up in three different

arrangements at each location. It took 19 minutes to relocate the winch and about 4 minutes to set up the snatch block. Some trees were winched as far as 150 feet; the average distance was about 60 feet. The average winch rate was about 150 feet per minute, and the average distance between piles of winched logs was 35 feet. Based on a fixed machine cost of $1.54 per SH for the winch, an operating cost of $1.75 per PH, a labor cost of $10.00 per SH, and a total production of 51.1 cords, the estimated cost of this harvesting phase was $9.43 per cord.

The forwarder averaged 3.9 cords per PH that amounted to 143 sticks per PH. It made 22 cycles, with an average trip distance of about 1,400 feet. The average load consisted of 2.3 cords or 85 sticks. Based on a fixed machine cost of $7.82 per SH, an operating cost of $8.19 per PH, and a labor cost of $10.00 per SH, the estimated cost of forwarding was $6.92 per cord that gives a combined cost to roadside of $25.00. Assuming the same trucking costs as in the mechanized system ($8.16/cord), the total cost was $33.16 per cord. The percent of total cost ranged from 21 percent for forwarding to 28 percent for winching, bucking, and piling.

In the labor-intensive system, the felling, delimbing, bucking, and piling were done by a two-man crew. The sawyer did the felling, delimbing, and bucking, while the second person acted as a helper by measuring 100-inch sticks, piling, clearing slash, and other minor duties. They averaged 13.5 trees per PH that produced 51.1 sticks or 2.2 cords per PH. Based on a total production of 36.8 cords and a labor cost of $10.00 per SH, the estimated cost of felling, delimbing, bucking, and piling shortwood at the stump was $11.84 per cord (table 11).

The Gafner 4501F forwarder averaged 4.3 cords per PH or 204 sticks per PH. The average round-trip distance was 720 feet for the 17 loads produced from 1.8 acres. The estimated cost of forwarding was $6.24 per cord that gives a combined cost to roadside of $18.08 per cord. Assuming the same trucking costs as in the mechanized system, the total cost was $26.24 per cord of which felling, delimbing, and bucking represented 45 percent and trucking 31 percent.

Of interest is a comparison of grapple skidding of tree-length logs in the mechanized operation with forwarding of shortwood in the semimechanized and labor-intensive systems. Although the grapple skidder had less than half the payload (about 0.9 cords/load) of the forwarder (about 2.3 cords/load), its higher travel speed and faster loading and unloading gave it twice the overall productivity of the forwarder. This higher productivity of the skidder did not significantly lower the cost of getting the material to the landing ($6.14 per cord for the skidder versus $6.24 to $6.92 per cord for the forwarder). The higher machine cost of the grapple skidder compared to the forwarder offsets the increased productivity, but this also suggests that a smaller grapple skidder should have been used.

In comparing the cost of producing roundwood at roadside and the delivered cost from the three systems, the mechanized operation gave the lowest cost with the labor-intensive system being a close second. The potential profit from each of these operations was determined by using the local firewood market. Stumpage was assumed to be $3.00 per cord, and overhead costs were assumed to be 15 percent for the mechanized operation and 5 percent for the other two systems. Using $38.00 per cord as the local value of firewood, the potential profit before taxes

was $6.64, $7.45, and $0.18 per cord for the mechanized, labor-intensive, and semimechanized systems, respectively.

Table 11.--Machine rate and cost for each harvesting phase of the labor-intensive system - Case IV.

Equipment type	Observed time		Machine rate		Total labor cost[b] ($)	Total cost ($)	Cost per cord[d] ($/cord)	Percent of total cost
	SH	PH	Fixed ($/SH)	Operating ($/PH)				
Chain saw	19.98	17.11	0.70[a]	1.29[a]	399.60[c]	435.66	11.84	45
Gafner 4501F forwarder	8.94	8.57	7.82	8.19	89.40	229.50	6.24	24
SUBTOTAL					489.00	665.16	18.08	
Shortwood truck[e]						300.29	8.16	31
TOTAL						965.45	26.24	100

[a]Two chain saws incurred fixed costs; one incurred operating costs.
[b]Labor cost is $10/SH.
[c]This was a two-man operation with one sawyer and one helper who piled shortwood, removed slash, etc.
[d]Based on total system production of 36.8 cords from 1.8 acres.
[e]The same trucking costs are assumed as in the mechanized system - Table 9.

The delivered cost per cord is the most important factor in any logging operation--especially so in marginal hardwood thinning operations. But there are other factors that should be considered, two of which are total capital investment and logging damage to the site and residual stand.

In this case study, the total capital investment of the mechanized harvesting system excluding trucking was $342,200; the semimechanized and labor-intensive systems required only $61,200 and $51,200 of investment, respectively. Only a limited number of loggers in the Lake States are able or willing to invest close to a half-million dollars in logging equipment. Therefore both mechanized and more labor-intensive systems should be considered in planning future thinnings.

Of the three systems studied in this case study, the least amount of damage to the residual stand was done by the semimechanized operation. By prebunching with the winch, the travel of the forwarder was limited to the strip road in the center of the plot.

It is interesting to note the difference in the productivity and cost of the mechanized harvesting in Case III (table 6) and Case IV (table 9). Felling

and bunching productivity in Case IV was about three to four times more than in Case III; skidding productivity in Case IV was about two to three times greater than in Case III. There are at least two reasons for this difference. One is that Case III was a pure selection thinning compared to the strip-selection thinning in Case IV. The strip-selection layout is obviously better suited to a mechanized operation by providing a well-marked route for the feller/buncher and skidder to follow. The second reason for this variation is the substantial difference in the amount of pulpwood produced per acre. In Case IV it amounted to 18.6 cords per acre compared to 2.0 to 4.1 cords per acre in Case III.

CASE V - 1982 STEEP SLOPE THINNING

The objective of this case study was to evaluate a commercially available feller/buncher in a strip-selection thinning on steep slopes. The study site consisted of 6.5 acres of northern hardwood poletimber located on the Munising Ranger District of the Hiawatha National Forest. The slope ranged from zero to 50 percent, and the average tree was 8.2 inches dbh. The stand consisted of 362 trees per acre (larger than 1.5 inches dbh) having a basal area of 132 square feet per acre, or 246 trees per acre (larger than 5.5 inches dbh) having a basal area of 122 square feet per acre. The major species were 52 percent sugar maple, 28 percent beech, and 20 percent red maple, black cherry, and yellow birch combined.

Strips were laid out every 45 feet up and down the slopes. A Timberjack Timbco Hydro-Buncher was selected as the feller/buncher most likely to successfully traverse the steep slopes. The Timbco felled and bunched the trees in the strips and selectively felled the marked trees between the strips, bunching them in the strips.

The average dbh of the 841 felled trees was 6.7 inches, the average number of trees per bunch was 5.6, and the Timbco productivity was 91 trees per PH. The cost of felling and bunching was estimated at $3.00 per ton or $7.50 per cord (assuming 2.5 tons equals 1 cord). The breakdown of the feller/buncher productive time is as follows: 18 percent for travel; 38 percent for shearing; and 44 percent for swinging and bunching.

SUMMARY

Northern hardwoods must be thinned to produce high value veneer and sawtimber in the long term. The major barriers have been the lack of markets for low-grade hardwoods and the low profit margin realized by the loggers in conducting the thinnings. New regional pulpwood and firewood markets have opened up for the Upper Peninsula of Michigan and northern Wisconsin. One of the most significant is the new Champion International pulp mill at Quinnessec, Michigan, which has increased interest in the equipment, methods, productivity, and cost of thinning northern hardwood poletimber.

Productivity and costs of five hardwood thinning case studies are presented in this paper. They range from fully mechanized whole-tree chipping operations to labor-intensive shortwood systems. Factors that affect productivity were not constant from one logging method or site to another. These factors include, but are not limited to, stand characteristics, plot size, skidding or forwarding distances, operator ability, weather, and unavoidable delays. Therefore the results presented are for specific case studies and do not imply long-term averages.

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Figure 1.--Timberjack Timbco Hydro-Buncher operating in a red oak poletimber stand.



Figure 2.--John Deere 640 grapple skidder bringing out its payload.

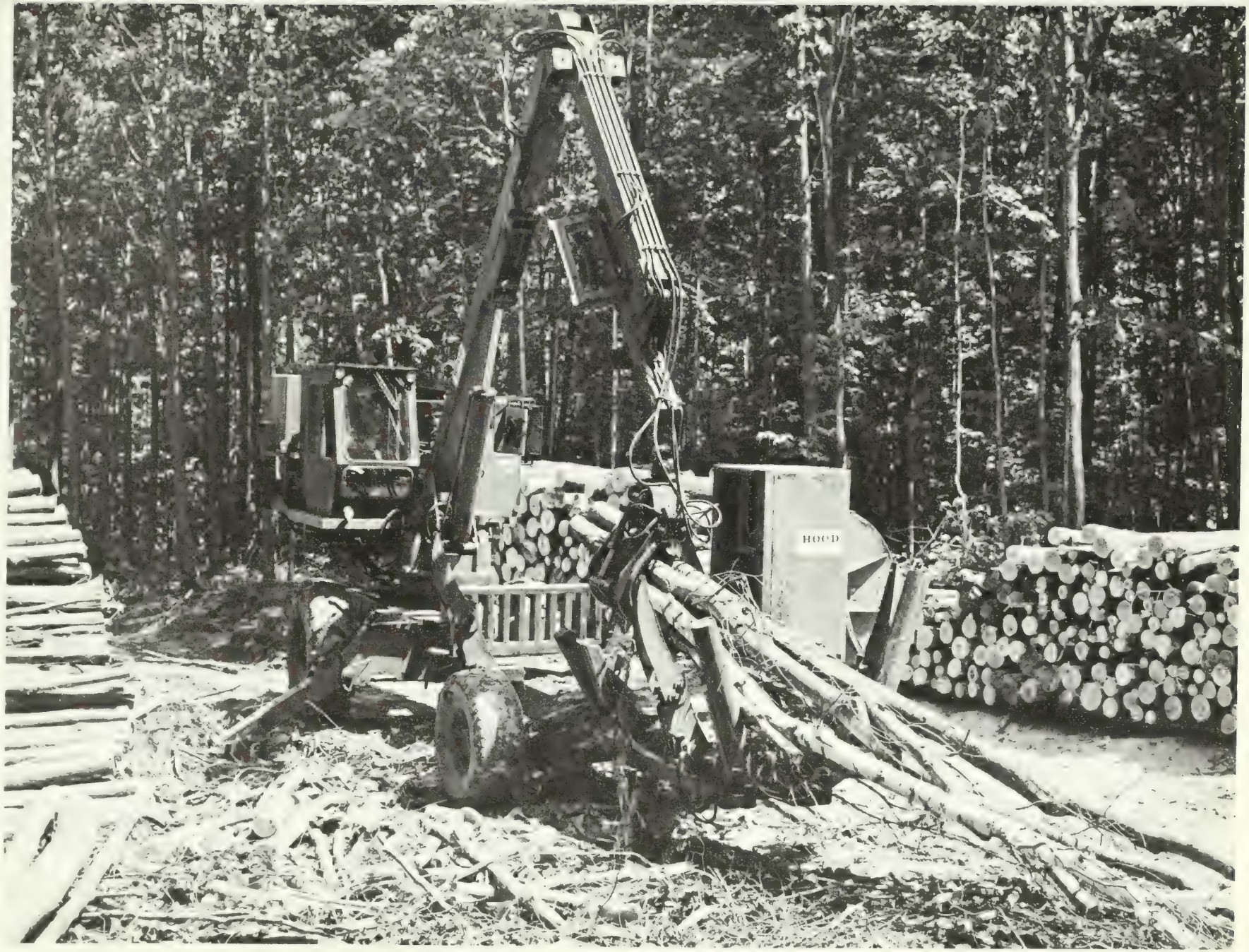


Figure 3.--Self-propelled Hood slasher producing pulpwood and firewood.



Figure 4.--Radio Horse winch anchored to a tree.



Figure 5.--Gafner Iron Mule forwarder loading shortwood from a bunch prepared by a radio-controlled winch.

A 9-YEAR EVALUATION OF MECHANIZED THINNING IN NORTHERN HARDWOODS

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Abstract.-- Nine-year results are reported for five thinning treatments in a young even-aged stand of northern hardwoods in Michigan's Upper Peninsula. Of the thinning treatments, two left more potentially good quality crop trees with less damage and better spacing: a selective treatment using chain saw felling with no product recovery and a mechanized strip treatment with selection between strips. Mechanized felling and skidding systems generally appear promising for making the first cuts in selectively thinned or even-aged stands and for making shelterwood regeneration cuts in even-aged stands.

In 1974 a study was begun to determine the the feasibility of using mechanized systems to thin dense pole-sized stands of northern hardwoods to provide hardwood pulpwood and to improve growth and quality of the residual trees. The cooperators in that effort were Michigan Department of Natural Resources; Ahonen Lumber Company of Ironwood, Michigan; and the North Central Forest Experiment Station's Laboratory in Houghton, Michigan.

In this paper we report preliminary 9-year results on how five different thinning treatments affected d.b.h. growth, basal area growth, stand structure, and quality development of potential crop trees. We also appraise damage to potential crop trees by treatments, evaluate sapling development under the shelterwood overstory, and attempt to determine the best thinning methods of those tested.

PROCEDURES

Description of the study area

In the fall and early winter of 1974, five thinning treatments were installed in a 50-acre stand of northern hardwoods on State forest land in Section 36, T51N, R37W, Ontonagon County, in the Upper Peninsula of Michigan. The 48-year-old stand was predominantly even aged and pole size, but it also contained a good proportion of small saw log size trees (10 to 14 inches d.b.h.) and some larger, older residual trees. Before thinning, the stand contained about 13.5 cords of hardwood pulpwood and 2,700 board feet of sawtimber. The stand averaged 217 trees per acre of which 55 percent were red maple and 25 percent were sugar maple; and it averaged about 100 square feet of basal area per

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acre (Biltonen et al. 1976). Smaller amounts of yellow birch, black cherry, red oak, hemlock, American elm, balsam fir, and black ash were also present. Site index at 50 years averaged about 60 for sugar maple. The soil is a sandy loam.

Treatments

Two 25-acre blocks, each 1,650 feet long by 660 feet deep, were laid out on each side of a logging road. Each block was divided into five 5-acre plots; each plot was 330 feet wide and extended 660 feet deep into the stand from the road (fig. 1).

The five thinning treatments included:

(1) Strip thinning only with mechanical felling and skidding.-- Plot A-1 was strip thinned with eleven 10-foot-wide clearcut strips. Ten 22-foot areas were left uncut between the 10-foot strips. Basal area before strip clearcutting was 109 square feet per acre in trees 6 inches d.b.h. and larger; residual basal area after cutting was 73 square feet per acre. Plot A-2 was strip thinned with nine 10-foot-wide clearcut strips; eight 30-foot areas were left uncut between the strips. Basal area before cutting was 94 square feet per acre; residual basal area was 68 square feet per acre.

(2) Strip thinning with selection between the strips and mechanical felling and skidding.-- Plots E-1 and E-2 were strip thinned with five 10-foot-wide clearcut strips. The four 70-foot-wide areas left between the strips were selectively thinned. Basal area before strip clearcutting and selective thinning on Plot E-1 was about 102 square feet per acre; residual basal area after thinning was 71 square feet per acre.

(3) Selection thinning with chain saw felling and no product recovery.-- Plots B-1 and C-1 were selectively thinned with a chain saw to leave a residual stand with 70 square feet of basal area per acre. Basal area before thinning on Plot C-1 was 126 square feet of basal area per acre; residual basal area after thinning was 65 square feet.

(4) Selection thinning with mechanical felling and skidding.-- Plots D-1 and D-2 were selectively thinned to leave a residual stand containing 67 square feet of basal area per acre. Basal area before thinning on Plot D-1 was 103 square feet of basal area per acre.

(5) Shelterwood thinning with mechanical felling and skidding.-- Plots B-2 and C-2 were marked to leave a residual shelterwood overstory stand with a high crown cover of about 70 percent or approximately 31,000 square feet of canopy cover per acre. Most thinning was done from below to develop the high crown canopy in the shelterwood overstory trees. Basal area before the shelterwood cut was 108 square feet per acre; residual basal area was about 60 square feet.

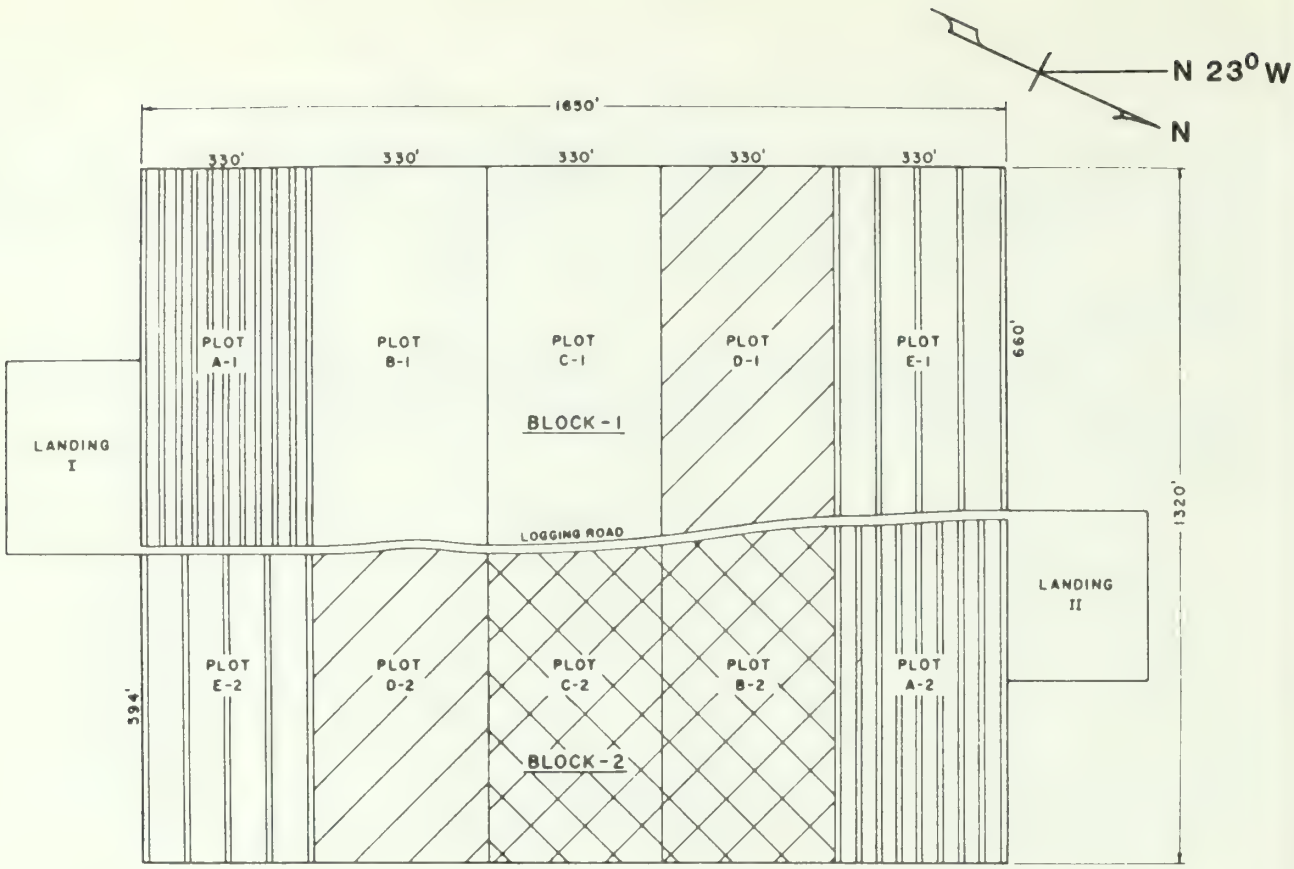


Figure 1.--Plot layout at the 1974 thinning study (Biltonen et al. 1976).

METHODS

In the fall of 1983, we remeasured d.b.h. and the extent of logging damage on trees that had been numbered and measured in 1974 on 6-foot-wide diagonals across plots A-2, B-2, C-2, D-2, and E-2. On each tree damaged by logging, we described the kind of injury and measured the location and the severity of each injury. Early in April 1984, we measured all trees 5 inches d.b.h. and larger on the center acre of one plot for each treatment in plots C-1, D-1, E-1, B-2, and C-2. We took these measurements to obtain a better sample for stand basal area growth and to get an idea of how the treatments affected potential crop trees and stand structure. We also inventoried the sapling reproduction on four randomly selected quarter-acre plots on shelterwood plot B-2 to determine how the reproduction was developing under the shelterwood cut.

RESULTS

Basal area growth

The limited data taken for this preliminary evaluation indicate that net basal area growth of all trees 4.6 inches d.b.h. or larger is quite variable. Basal area growth ranged from a low of 1.3 square feet to a high of 3.93 square feet per acre (table 1). We do not expect that such large differences between the treatments will remain once we have completely sampled the treatment areas for our 10-year evaluation.

An existing model for periodic net basal area growth in relation to beginning basal area for all trees 4.6 inches d.b.h. and larger indicates that net basal area growth for all these treatments should only vary from about 3.0 to 3.3 square feet per acre per year (Erdmann and Oberg 1973). The summers of 1974 through 1976 were extremely droughty, however, and basal growth generally averaged somewhat lower than we expected.

Diameter growth

Diameter growth at breast height varied more by species and original tree size class than by specific thinning treatments or residual stocking levels. Trees averaging 9.7 inches d.b.h. in the shelterwood treatment had a higher average annual d.b.h. growth than did trees averaging 6.8 to 9.0 inches in diameter in the other thinning treatments (table 2). In addition to having larger diameter trees initially, the shelterwood treatment also had the lowest residual basal area density following thinning. As a result of these two factors, the residual shelterwood overstory trees grew faster than trees left in the other treatments.

Our growth model for mean annual d.b.h. growth in relation to beginning basal area predicts about .23 inches of mean annual diameter growth for small saw log-size trees when starting with 60 square feet of basal area per acre (Erdmann and Oberg 1973). It also predicts .15 to .17 inches of mean annual diameter growth for pole-size trees when starting with 64 to 73 square feet of basal area per acre. Like basal areas, diameter increments were also lower than expected.

Table 1.-- Beginning and ending basal areas and average annual basal area growth by thinning treatments over a 9-year period following thinning

Thinning treatment	Basal area		Average annual basal area growth
	Beginning	Ending	
	-Sq.ft./A.-	-Sq.ft./A.-	-Sq.ft./A.-
Selection, chain saw felling and no product recovery (Plot C-1)	63.9	81.2	1.92
Selection, mechanical felling and skidding (Plot D-1)	65.7	101.1	3.93
Strips-with-selection, mechanical felling and skidding (Plot E-1)	70.6	82.3	1.30
Strip only, mechanical felling and skidding (Plot A-2)	68.6[a/]	91.6	2.56
Shelterwood, mechanical felling and skidding (Plot B-2)	60.5	78.2	1.97

a/ Based on 27.27 percent cut of the initial stand basal area in 1974.

Table 2.--Beginning and ending average d.b.h. and average annual d.b.h. growth by thinning treatments over a 9-year period following thinning

Thinning treatment	Average d.b.h.		Average annual d.b.h. growth
	Beginning	Ending	
	-Inches-	-Inches-	-Inches-
Selection, chain saw felling and no product recovery (Plot C-1)	8.50	9.74	0.14
Selection, mechanical felling and skidding (Plot D-1)	8.99	10.36	0.15
Strips-with-selection, mechanical felling and skidding (Plot E-1)	8.71	9.93	0.14
Strip only, mechanical felling and skidding (Plot A-2)	6.78	8.04	0.14
Shelterwood, mechanical felling and skidding (Plot B-2)	9.66	11.47	0.20

Stand structure

Stand structure in the mechanical selection, strip-with-selection, and chain saw selection plots (C-1, D-1, E-1) has changed considerably because of ingrowth into the saw log d.b.h. classes during the 9-year period following thinning (table 3). The number and basal area of stems has increased in the saw log diameter classes, but has decreased in the pole-size class. After 9 years, the only treatment that appears to be overstocked in both sawtimber and pole-size classes is the selection thinning with mechanical felling and skidding treatment.

Although none of the selection treatments will have an operable cut within 10 years after the initial cut, the expected mean annual net basal area growth of 2.5 to 2.8 square feet per acre for residual basal areas ranging from 82 to 100 square feet per acre (Erdmann and Oberg 1973) should produce operable cuts of 20 to 30 square feet per acre after another 10-year growth period.

Sapling development under the shelterwood cut

Only two sapling-size (0.5 to 4.5 inches d.b.h.) stems were present per acre immediately after the shelterwood cut was made in 1974 to leave a high shelterwood canopy containing about 70-percent crown cover. Nine years later, 2,085 saplings over 6 feet tall were well distributed per acre (table 4). Sugar maple accounted for more than 63 percent of these stems and more than 55 percent of the sapling basal area; red maple accounted for more than 34 percent of the stems and almost 42 percent of the basal area. Together these species made up more than 97 percent of the sapling stems and basal area. Small amounts (1 percent each) of yellow birch and black cherry were also present.

Most sugar maple stems inventoried appeared to be of seedling or seedling sprout origin, while most red maple stems were of sprout origin. Numbers of companion red maple stump sprouts have already declined drastically because of normal competitive mortality.

The new stand under the shelterwood overstory is well established and ready for the final overstory removal cut. It contains 38 percent more sugar maple stems and 23 percent fewer red maple stems than the original 1974 stand before thinning. Successional trends on this upland site are normal; moderately tolerant overstory red maples are gradually being replaced by more tolerant understory sugar maple trees in the absence of fire. This is a desirable improvement in species composition because red maple tends to be more defective than sugar maple on this site.

Damage to crop trees

In the spring of 1984, we recorded three types of injuries; those to the bole, root, and crown. Crown injuries, as reported previously, were again found to be of minor importance (Biltonen et al. 1976). Fifty out of 53 injuries or 94 percent of the injuries found on damaged crop trees were bole injuries, the remaining three injuries were a combination of both bole and root injuries.

A crop tree was considered seriously damaged when it had an injury 50 square inches or larger (Hesterberg 1957). Wounds initially under 50 square

Table 3.--Stand structure in the selection thinning plots (C-1, D-1, and E-1)

D.b.h. class	After cut in 1974				After 9 years				Selection goal			
	Trees		Basal area		Trees		Basal area		Trees		Basal area	
-Inches-	-No./A.-		-Sq.ft/A.-		-No./A.-		-Sq.ft./A.-		-No./A.-		-Sq.ft./A.-	
5-9	102		30		76		24		65		16	
10-14	31		22		52		38		28		22	
15-19	9	41	14	36	14	68	22	65	17	53	26	68
20+	1		1		2		5		8		20	
Total	143		67		144		89		118		84	

Table 4.--Sapling development 9 years after the shelterwood cut (Plot B-2)[a/]

Species	Saplings	Basal area
	-No./A.-	-Sq.ft./A.
Sugar maple	1,324	7.5
Red maple	712	5.7
Yellow birch	23	0.2
Black cherry	23	0.2
Other hardwoods	1	-[b/]
Conifers	1	-[b/]
Total	2,085	13.6

a/ Trees 1 to 4.5 inches in d.b.h.

b/ Less than 0.1 square feet of basal area per acre.

inches on crop trees in 1974 were usually healed over or closed after 10 years and were considered to be of minor significance.

The strip thinning plot(A-2) with the smallest average beginning stand diameter (6.8 inches) and the closest average spacing of 11.2 feet between trees had the highest number (12) of seriously damaged crop trees per acre (table 5). While strip thinning, the operator placed all cut trees from the clearcut strip into the uncut stand. This required repeated placement of small bunches and many back up movements by the feller-buncher with trees in the acccumulator head, which resulted in increased damage.

Selection thinning with mechanical felling and skidding had the second highest damage rate with 10 seriously damaged crop trees per acre (Plot D-1).

The shelterwood thinning with mechanical felling and skidding had the third highest damage rate with seven seriously damaged crop trees per acre (Plot B-2).

Only two trees per acre were seriously damaged on the mechanical strip-with-selection plot (E-1).

No seriously damaged crop trees were found on the selection thinning with chain saw felling and no product recovery plot (C-1). Chain saw felling causes some minor crown injuries but few bole and root injuries. Most of the bole and root injuries are caused by skidding; the rest are caused by the skidder or feller buncher actually bumping trees. Undoubtedly, some damage would have occurred to crop trees in the chain saw felling plots if the felled trees would have been skidded to a landing.

MANAGEMENT IMPLICATIONS

Silviculturally, selection thinning and strip thinning with selection between strips are better than strip thinning-only because they offer greater opportunities for: (1) selecting and releasing more high-quality crop trees, (2) concentrating growth more uniformly on those trees, and (3) limiting damage to crop trees during thinning.

For example, the strip thinning-only plot (A-2) had about 75 potential crop trees before the nine 10-foot-wide by 660-foot-long strips were clearcut through the 5-acre plot. This strip treatment removed 20 potential crop trees per acre and left 55 (table 6). If five 10-foot wide clearcut strips would have been used instead of the nine, only 11 potential crop trees would be cut and 64 would be left. If eleven 10-foot wide clearcut strips were used, 25 potential crop trees would be cut and only 50 would be left.

Thirty-three of 59 potential crop trees remaining after strip clearcutting with nine 10-foot-wide strips (Plot A-2) were saw log-size trees; the 26 remaining trees were poles (table 7). After we deduct potential crop trees with serious damage ($\geq$ 50 square inch wounds), only 24 saw log-size and 23 pole-size potential crop trees remain. This is not enough saw log-size crop trees for even-age management, but the stand still could be developed under uneven-age management with adequate numbers of saw log-size trees (47 out of 53 trees)

Table 5.--Effect of the five thinning treatments on potential crop trees after 9 years

Thinning treatment	Injuries	Types of injuries			Seriously damaged[a/]
		Skidding	Machine	Felling	
	-No./A.-		-Percent-		-No./A.-
Selection, chain saw felling and no product recovery (Plot C-1)	0	-	-	0.0	0
Strip-with-selection, mechanical felling and skidding (Plot E-1)	2	100.0	0.0	0.0	2
Shelterwood, mechanical felling and skidding (Plot B-2)	12	41.7	50.0	8.3	7
Selection, mechanical felling and skidding (Plot D-1)	15	33.3	53.3	13.3	10
Strip only, mechanical felling and skidding (Plot A-2)	24	62.5	29.2	8.3	12
Total mechanical felling and skidding	53	237.5	132.5	29.9	31
Average	13.2	59.4	33.1	7.5	7.8

[a/] Trees lost as potential crop trees due to a wound or combination of nearby wounds with more than 50 square inches of sapwood exposed.

Table 6.--Effect of the number of 10-foot wide clearcut strips on the number of potential crop trees cut and left after cutting a 5-acre plot 330 feet wide by 660 feet long

Ten-foot clearcut strips	Percent of area clearcut	Potential crop trees		
		Before cut	Cut	After cut
-Number-	-Percent-	-Number per acre-		
5	15.2	75	11	64
9	27.3	75	20	55
11	33.3	75	25	50

Table 7.--Effect of thinning treatments on the number of potential crop trees in sawtimber- and pole-size classes 9 years after thinning

Thinning treatment	After thinning in 1974[a/]			After 9 years[b/]		
	Saw log	Pole	Total	Saw log	Pole	Total
	-Number per acre-					
Selection, chain saw felling and no product recovery (Plot C-1)	46	17	63	46	17	63
Strip-with-selection, mechanical felling and skidding (Plot E-1)	42	15	57	41	14	55
Selection, mechanical felling and skidding (Plot D-1)	48	21	69	41	18	59
Shelterwood, mechanical felling and skidding (Plot B-2)	44	-	44	37	-	37
Strip only, mechanical felling and skidding (Plot A-2)	33	26	59	24	23	47

a/ Without deductions for seriously damaged trees.
b/ With deductions for seriously damaged trees (with more than 50 square inches of sapwood exposed wounds in 1974).

appearing from ingrowth within the next 20 years. Management options for five clearcut strips are better; for 11 clearcut strips they are worse.

Although the average d.b.h. of the residual overstory stand was too small (11.5 inches) for making a shelterwood cut under normal even-age circumstances, the shelterwood treatment demonstrates the economic feasibility of using mechanized felling and skidding for making the initial shelterwood regeneration cut in even-aged stands. Shelterwood cuts are also desirable for replacing low-quality northern hardwood stands of seed bearing age on good sites with adequate regeneration of higher quality stems or more desirable species.

On the shelterwood treatment (Plot B-2), 16 percent of the 44 potential saw log-size crop trees per acre or seven trees were seriously damaged. For a young stand, this level of damage is considered serious; but with mature residual trees in a shelterwood overstory left for only 5 to 8 years before the final removal cut, almost no losses would occur because the damaged wood would be slabbed off when sawn.

The selection thinning with chain saw felling and no product recovery treatment (Plot C-1) lost no potential crop trees because of damage. This left 46 potential crop tree-size saw logs and 17 poles per acre (table 7). On the strip-with-selection treatment (Plot E-1), only 4 percent of the potential crop trees or two trees per acre were lost to damage; leaving 41 potential crop tree-size saw logs and 14 poles per acre. On the selection thinning with mechanical felling and skidding treatment (Plot D-1), 14 percent of the potential crop trees or 10 trees per acre were lost to damage, leaving 41 potential crop tree-size saw logs and 18 poles per acre. Each of these selection treatments will have more than enough saw log-size crop trees for uneven-age management within the next decade. During subsequent thinning operations, major emphasis must be placed on protecting crop trees or little high-quality wood will be produced. As a result, mechanized logging methods will have to be somewhat restricted to eliminate any damage to the crop trees.

Skidding appears to be the major problem in damaging trees. Most of the damage in future thinnings could be prevented by using short wood (100-inch) skidding systems and by not harvesting during the spring bark slip season. Root and stem injuries can be minimized by logging when the ground is frozen. Skidder operators should be trained to stay on skid trails and to recognize and prevent damage. And finally, leaving poor-quality barked-up pivot trees until the end of the next thinning operation would prevent further damage.

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EVALUATION OF 1978 THINNING SITE

James A. Johnson[1/]

Abstract.--A strip selection thinning was conducted to determine the economic and silvicultural implications of a mechanized harvesting system. The selectively cut strips were thinned from an original basal area of 116 square feet per acre to a residual of 68 square feet. Individual tree diameter growth increased from 0.11 inches per year on the control to 0.20 inches per year on the thinned plots, an 82-percent increase. The increased length growth of trees on the thinned plots of 607-percent over the control, plus the diameter increase, provided a 92-percent cubic foot increase on cordwood trees and 107-percent board foot increase on sawlog trees.

The 1978 thinning study was located in Sections 1 and 2, T45N-R22W, in Alger County, Michigan and co-sponsored by Michigan Technological University, North Central Forest Experiment Station of the U.S. Forest Service, Michigan Department of Natural Resources, Marquette Board of Light and Power, and the Michigan Department of Commerce--Energy Administration.

The specific objectives were: (1) to test strip-with-selection thinning by means of a tracked, long-reach feller-buncher; (2) to determine production rates and costs for harvesting and transporting; (3) to evaluate residual damage and effects of compaction caused by harvesting equipment; (4) to measure tree response and reproduction established as a result of mechanized thinning; and, (5) to determine logistics and economics of utilizing chips as an alternate fuel for generating electricity in a conventional coal burning boiler.

The harvesting rates and costs, residual damage, and compaction were reported by Johnson, et al (1979). Objective (4) growth response, is reported in this paper.

STUDY AREA AND METHODS

The predominately pole-sized stand of 13 acres was composed of 73-percent sugar maple, 22-percent American elm and the remaining 5-percent was basswood, quaking aspen and black cherry. The stocking level before cutting was 254 trees per acre (average tree diameter 9 inch d.b.h.) and 116 square feet per acre of basal area. Because of severe incidence of Dutch elm disease, it was necessary to harvest all of the elm. This precluded the possibility of maintaining a desired uniform stocking of 70 square feet of basal area in these areas where elm predominated.

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The control area was sampled with three one-fifth acre study plots and the thinned area with four one-fifth acre study plots. The plots were measured prior to harvesting in 1978 followed by a four year remeasurement. All trees 5 inches d.b.h. to a fixed minimum top diameter of 4 inches inside bark were measured. In addition sawlog size trees 11 inches d.b.h. and larger were measured to a variable top diameter with an 8 inch minimum inside bark diameter.

RESULTS

One of the major objectives of the study was to measure growth response and quality change following harvest. The following three tables summarize the changes four years after harvest.

Individual Tree Growth Comparisons

Table 1 summarizes the differences in growth response of individual trees on the control plots with those on the thinned plots. Diameter growth increased from .11 inches on the controls to 0.20 inches on the thinned trees, an 82-percent increase. A tree growing at the slower rate would take 146 years to reach 16 inches d.b.h. while a tree growing at the faster rate would only take 80 years, or 45-percent less time. Another example of the benefits derived from thinning is to compare the differences in carrying costs. At compound interest, the length of time the carrying charges (land and timber ownership) must be carried to produce mature timber is significant. For example, a one dollar carrying charge compounded at 7-percent for 40 years (time to grow an 8 inch tree to 16 inches at the faster rate) equals $14.97; at 73 years (time to grow an 8 inch tree to 16 inches at the slower rate) it would be $141.52. The carrying cost is 845-percent greater for the slower growing tree. Reducing the length of time to harvest, therefore, will greatly reduce investment costs and thereby yield a greater net return.

Table 1.--Individual tree growth comparisons of thinned and unthinned trees over a four year period.

Growth Component	Average Growth Per Tree Per Year				
	Control		Thinned		
	Growth	No. Trees	Growth	No. Trees	% Change
Diameter (in.)	0.11	154	0.20	85	82
Usable Length (Ft.)(4"Top) (Cordwood Trees)	0.14	157	0.99	85	607
Cubic Feet (Cordwood Trees)	0.26	162	0.50	94	92
Board Feet (Sawlog Trees)	2.70	25	5.60	18	107

An increase in usable length growth from .14 feet per year on the control compared with .99 feet on the thinned plots is 607-percent greater, a significant difference. This increased length and diameter growth translates into a 92-percent increase in cubic foot volume growth of the thinned cordwood trees over the non-thinned trees and a 107-percent increase in board foot volume of the sawlog trees.

Tree Quality Comparisons

Table 2 summarizes the changes in tree quality. Each tree in the study plots where graded by a tree grading system devised by Boyce and Carpenter (1968). The grading system is correlated with the Forest Service grade specifications for hardwood sawlogs. The grades are assigned according to the probability of a tree yielding a grade-1, grade-2, or grade-3 butt log when it reaches 16 inches d.b.h.

Table 2.--Tree quality changes following thinning.

Tree Quality[1/]	Trees/Acre				% Change
	Control	%	Thinned	%	
0	36.7	14	8.8	8	-43
1	46.7	18	22.5	19	6
2	138.3	52	78.8	67	29
3	43.3	16	7.5	6	-62
TOTAL	265.0	100	117.6	100	

1/ Boyce and Carpenter, 1968, USDA For. Serv. Res. Pap. NE-97.

The grades are defined as follows:

A grade-0 growing-stock is a softwood or hardwood tree with no potential for developing into sawlogs.

A grade-1 growing stock tree has 80-percent probability of yielding a grade-1 butt log.

A grade-2 growing stock tree has less than 80-percent probability of yielding a grade-1 butt log, but a 50-percent chance or better of yielding a grade-2 butt log.

A grade-3 growing stock tree has less than a 50-percent probability of yielding a grade-2 butt log, but a 50-percent chance or better of yielding a grade-3 butt log.

The first priority in thinning is to remove as many of the 0-grade trees as possible. Grade-0 trees were reduced from 14-percent to 8-percent a 43-percent reduction. The second priority removal was grade-3 trees, which were reduced from 16-percent to 6-percent a 62-percent reduction.

Removal of these lower grade trees increased percentage of grade-1 trees by 6-percent and grade-2 trees by 29-percent over the controls. One of the major goals of thinning hardwoods is to increase the growth on the higher quality trees and to reduce the time needed to bring them to maturity.

Net Annual Growth Per Acre

Table 3 summarizes the changes in net annual growth per acre. As a result of reduced stocking total cubic foot volume growth was reduced from 92.23 cubic feet per acre per year on the controls to 76.38 cubic feet on the thinned plots, a 17-percent reduction. The thinned plots have 56-percent less trees, but are growing 83-percent of the volume of the controls. As full stocking is attained annual growth will again equal or exceed the controls.

Table 3.--Net annual cubic feet growth comparisons of thinned and unthinned plots.

Growth Components	Net Annual Growth/Acre (Cu. Ft.) Control	Thinned	% Change
Ingrowth	1.26	3.98	216
Cordwood Repeaters	54.34	41.83	-23
Cordwood to Sawlog	2.27	5.60	147
Sawlog Repeaters	33.71	24.97	-26
Cordwood Mortality	-33.18	0	-100
Sawlog Mortality	-13.43	0	-100
Sawlog to Cordwood	0.65	0	-100
TOTAL EXCLUDING MORTALITY	92.23	76.38	-17
TOTAL INCLUDING MORTALITY	45.62	76.38	67
CUT VOLUME	0	382.8	100
TOTAL NO. TREES	270	118	-56

If mortality is considered, a major difference in production results. The controls lost 45.62 cubic feet per acre per year to mortality resulting in 40-percent less cubic feet net growth than the thinned plots. This mortality was recovered in the thinnings, thus providing a greater total volume yield per acre on the thinned plots.

When the cut volume of 95.7 cubic feet per acre per year is added to the net growth of 76.38 cubic feet the yield of thinned over unthinned is 277-percent greater. Periodic thinnings has the potential of capturing much of the volume that would otherwise succumb to mortality, thus providing greater total volume recovery over the rotation.

CONCLUSIONS

Thinning over-stocked hardwood pole-sized stands can result in major increases in diameter and volume growth over unthinned stands. Time required to reach maturity can be 45-percent less on thinned trees than unthinned trees. Periodic thinnings provide opportunity to concentrate growth on quality trees by removal of the low quality inferior growing stock. Thinnings also provide opportunity to utilize volumes that would otherwise be lost to mortality, thus increasing total volume yields over the rotation.

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DAMAGE TO THE RESIDUAL STAND RESULTING FROM MECHANIZED THINNING OF NORTHERN HARDWOODS

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Abstract.--There is a definite need to standardize logging damage studies in order to facilitate meaningful comparisons between alternative thinning systems. Factors contributing to logging damage severity can be evaluated only through integration of damage study into harvest studies themselves.

Logging damage is most significant in stands managed under the selection system for sawtimber production and appears to be related to residual basal area. Damage may be minimized by reducing residual basal area, by favoring smaller and more maneuverable equipment, by avoiding spring and early summer thinning, by leaving 'bump' trees along paths of equipment travel, by marking crop trees, by increasing the skills and pride of equipment operators, and by marking stands to be thinned with full knowledge of the equipment to be used.

Logging damage is a concern of hardwood forest land owners deciding how, if at all, to harvest their resource. Choice of silvicultural system and harvesting equipment interact with operator skill and diligence to determine the extent of damage done to the residual stand and the value loss associated with that damage. Earlier studies have documented logging damage caused by conventional chainsaw felling in combination with various types of skidding equipment (Herrick and Deitschman 1956, Benzie 1959, Meyer et al. 1966, Lamson et al. 1984). Generally, skidding damage increases with equipment size and load size. It follows that substitution of mechanized thinning equipment for the chainsaw (Biltonen et al. 1976) can increase the expected frequency and severity of logging damage. For this reason, the extent of logging damage to residual stems in a number of mechanically thinned hardwood pole stands is being evaluated in conjunction with the U.S. Forest Service, North Central Forest Experiment Station, Houghton, Michigan. The objectives of these studies are 1) to conduct an immediate inventory of damage to the residual stands, 2) to evaluate the long-term effects of logging damage on residual stand quality, and 3) to identify means by which logging damage may be reduced.

Slower healing and greater defect can be expected to result from gouged wounds of similar size to wounds without wood penetration. Wood penetration, or gouging, is a common feature of feller/buncher wounds. Earlier reports do not mention wood pene-

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tration or gouging, although some probably occurred. In contrast to earlier studies, however, the thinning studies reported here involve mechanized felling and bunching as well as mechanized skidding.

Classic logging damage studies have frequently used wound surface area as one criterion to separate smaller inconsequential wounds from wounds sufficiently large to result in meaningful defect. Ohman (1970) used an index of surface area derived by multiplying maximum wound length by maximum wound width; he considered 50 sq.in. to be a useful threshold for evaluating root wounds on yellow birch and stem wounds on both yellow birch and sugar maple. Lavallee and Lortie (1968) also reported that mechanical injuries greater than 50 sq.in. in surface area could be considered important on yellow birch. Hesterberg (1957) found that 10-year-old stem wounds on sugar maple which originally exposed more than 150 sq.in. of surface area had a 50 percent chance of being associated with decay. Twenty-year-old sugar maple wounds greater than 60 sq.in. in area also had a 50 percent chance of being associated with decay.

Hesterberg (1957) also determined that wound width was related to the likelihood of defect development. After 10 years, over 50 percent of all sugar maple stem scars originally greater than 7 inches in width had given rise to decay. After 20 years, over 50 percent of all sugar maple stem scars 4 inches or wider had given rise to decay.

METHODS

Two thinning studies have been investigated to date. The first study comprises a 1981 mechanized selection thinning in pole-size northern hardwoods near Watersmeet, Michigan, on the Ottawa National Forest, in Michigan's Upper Peninsula. Three adjacent blocks of timber totaling approximately 21 acres were thinned with three different whole-tree feller/bunchers[1/]. Details of the thinning in each block are as follow.

Watersmeet A:

- Date of Harvest - June, 1981
- Area - 6.46 acres
- Initial Basal Area - 124.1 sq. ft. per acre
- Cut Basal Area - 37.5 sq. ft. per acre
- Residual Basal Area - 86.6 sq. ft. per acre
- Feller/Buncher - Melroe Bobcat Model 1075 with a 16 inch capacity shear mounted on a wheel-type undercarriage with tandem over-tire tracks

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[1/]The use of trade, firm or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture or Michigan Technological University to the exclusion of others which may be suitable.

Watersmeet B:

Date of Harvest - June, 1981
Area - 6.84 acres
Initial Basal Area - 139.1 sq. ft. per acre
Cut Basal Area - 43.5 sq. ft. per acre
Residual Basal Area - 95.6 sq. ft. per acre
Feller/Buncher - Timbco Hydro-Buncher Model 2518 with an 18 inch capacity shear mounted on a knuckle boom and a track-type under-carriage

Watersmeet C:

Date of Harvest - August, 1981
Area - 7.76 acres
Initial Basal Area - 148.5 sq. ft. per acre
Cut Basal Area - 35.4 sq. ft. per acre
Residual Basal Area - 113.1 sq. ft. per acre
Feller/Buncher - Omark Hydro-Ax Model 311 with a 16 inch capacity shear mounted on the front end of a wheel-type undercarriage

Though one of the initial objectives of the Watersmeet thinning study was to compare the damage caused by the three feller/bunchers employed, this objective was dropped in light of the differences in stand structure between thinning blocks and the consequent differences in marking strategy. Unfortunately, resources permitted only feller/buncher wounds to be recorded for this study.

The second study comprises a 1982 strip-thinning with selection between the strips, conducted on approximately four acres of hardwoods dominated by red oak, managed by the Wisconsin Department of Natural Resources, near Spooner, Wisconsin. Due to the timing of this study, skidding wounds (along the cleared strip) as well as feller/buncher wounds were recorded together. Details of the thinning are as follow.

Spooner A:

Date of Harvest - June, 1982
Area - 4.1 acres, including strips.
- 2.8 acres, thinned area.
Initial Basal Area - undetermined.
Cut Basal Area - undetermined.
Residual Basal Area - 133.7 sq. ft. per acre, thinned area.
Feller/Buncher - Timco Hydro-Buncher Model 2518 with an 18 inch capacity shear mounted on a knuckle boom and a track-type under-carriage

In both studies, a 100 per cent survey was conducted of all injuries to stems over 1.0 inch d.b.h. The non-random spatial distribution of injury in each stand, resulting from the concentration of damage around paths of equipment passage, precluded less intensive sampling. Each feller/buncher operator in the Watersmeet study entered the stand wherever and as often as he saw fit, while the operator at the Spooner site was restricted to

reaching into the residual stand from the cleared strips.

All injuries which penetrated sufficiently to expose live inner bark were documented. The location of each injured tree was recorded by its azimuth and distance from permanent reference points in each stand. Wounded trees were characterized by species, diameter (d.b.h.), and location in the stand. Wounds were characterized by median height above ground, maximum vertical length, maximum horizontal width, depth of wood penetration, a descriptive code, and a color transparency of the injury.

RESULTS

At the Watersmeet thinning site, 989 wounds on 519 stems have been characterized and their locations in the three thinning blocks documented. At the Spooner thinning site, 635 wounds on 505 stems have been similarly documented.

Logging damage appears to be related to residual basal area and stocking (Table 1). As residual basal area increases, the percentage of residual basal area representing wounded stems generally increases, given comparable diameter distributions. The possibility exists, nevertheless, that portions of the differences in damage sustained by the four thinning blocks could be due to 1) physical factors of the different feller/bunchers themselves and/or 2) differences in the amount of basal area marked for removal in the different blocks. Interestingly, the Spooner block had both the largest residual basal area and the largest percentage of residual basal area wounded of all four thinning blocks. In the Watersmeet study, the thinning block sustaining the most damage (Block C) was also the block with the highest initial and residual basal area values and the lowest cut basal area. Unfortunately, skidding damage can not be separated from feller/buncher damage in the Spooner study, though skidding damage must have been concentrated along strip edges where bunches

Table 1.--Percentages of residual basal area and density damaged in four mechanically thinned hardwood stands

Stand	Residual Stand			
	Basal Area		Density	
	Total (sq. ft. per acre)	% of Total Wounded[c]	Total (no. stems per acre)	% of Total Wounded[c]
Watersmeet A[a]	87	6	744	18
Watersmeet B[a]	96	5	626	14
Watersmeet C[a]	114	13	527	40
Spooner A[b]	134	45	634	22

a/ includes only feller/buncher wounds
b/ includes skidding as well as feller/buncher wounds
c/ does not include destroyed stems

were deposited. Watersmeet data were collected prior to skidding. A survey of feller/buncher versus skidding injuries on two one-fifth-acre plots in each Watersmeet block, conducted by ranger district personnel, suggests that skidding damage was comparable in frequency to feller/buncher damage in each block.

At both study sites, stems were considered destroyed if they were severely bent or pushed over. In this sense, less than 1 per cent of the residual basal area or density on the Watersmeet study site was destroyed. On the Spooner site, however, 4 per cent of the residual basal area (7 per cent of the residual density) was destroyed. This included 12, 13, and 4 per cent of the 2 inch, 4 inch, and 6 inch diameter classes, respectively.

The frequency with which wounds meeting certain criteria of severity occurred on each of the four thinning blocks is presented in Tables 2 through 5. The relatively greater number of severely wounded trees on Watersmeet Block C than on Blocks A and B is over-shadowed by the data from Spooner. While a portion of the damage at Spooner is certainly due to skidding, other factors must have contributed to the greater severity of damage there than at Watersmeet. Such factors may include greater residual basal area, season of harvest, harvesting system design, and/or differences between equipment operators.

Table 2.— Numbers of stems wounded or destroyed by feller/buncher activity at Watersmeet Block A, and frequency with which selected criteria of wound severity were met, expressed as per cent of residual stocking by diameter class

dbh class (inches)	Residual stocking	Stem count (per acre)											
		Wounded or destroyed		Wound at least 7 in. wide		Wound at least 4 in. wide[c]		Wound LxW at least 50 sq. in.[d]		Wood penetrated or gouged		Broken top	Destroyed
		Roots[a]	Stems[b]	Roots	Stems	Roots	Stems	Roots	Stems	Roots	Stems		
2	382	0.3	1.9	---	---	---	---	---	0.2	---	0.5	---	0.8
4	143	0.8	5.6	---	0.3	---	1.2	---	1.9	0.3	2.3	0.3	1.5
6	132	0.6	5.7	---	0.8	0.2	2.6	0.2	2.3	0.6	2.5	---	0.3
8	60	0.9	3.6	0.3	0.6	0.3	1.5	0.3	1.5	0.8	2.0	---	---
10	20	0.9	1.7	---	0.5	---	0.8	0.3	0.9	0.6	0.9	---	---
12	4	0.2	0.5	---	0.3	---	0.5	---	0.5	---	0.5	---	---
14	2	0.2	0.8	---	0.2	0.2	0.6	0.2	0.8	0.2	0.3	---	---
16	1	0.2	0.2	---	---	0.2	0.2	0.2	0.2	---	0.2	---	---
18	1	---	---	---	---	---	---	---	---	---	---	---	---
Total	745	4.1	20.0	0.3	2.7	0.9	7.4	1.2	8.3	2.5	9.2	0.3	2.6

a/Mean height above-ground less than 2 in.; does not include injuries below-ground.
b/Mean height above-ground at least 2 in.
c/Includes wounds 'at least 7 in. wide'.
d/Estimated by multiplying maximum vertical wound length by maximum horizontal wound width.

Table 3.— Numbers of stems wounded or destroyed by feller/buncher activity at Watersmeet Block B, and frequency with which selected criteria of wound severity were met, expressed as per cent of residual stocking by diameter class

dbh class (inches)	Residual stocking	Stem count (per acre)											
		Wounded or destroyed		Wound at least 7 in. wide		Wound at least 4 in. wide[c]		Wound LxW at least 50 sq. in.[d]		Wood penetrated or gouged		Broken top	Destroyed
		Roots[a]	Stems[b]	Roots	Stems	Roots	Stems	Roots	Stems	Roots	Stems		
2	196	---	0.7	---	---	---	---	---	---	---	0.1	---	0.4
4	205	0.3	3.1	---	0.1	---	0.6	---	1.0	0.3	1.0	---	0.3
6	128	0.9	5.1	---	0.6	0.1	2.5	0.3	2.6	0.9	3.2	---	---
8	63	1.0	1.9	0.1	0.1	0.1	0.6	0.1	0.4	0.6	0.7	---	---
10	21	1.2	1.5	0.1	---	0.6	0.3	0.9	0.4	0.9	0.6	---	---
12	3	0.1	0.1	---	0.1	---	0.1	---	0.1	---	0.1	---	---
14	5	0.3	0.6	0.1	0.1	0.1	0.3	0.3	0.4	0.3	0.3	---	---
16	3	0.1	0.3	---	---	0.1	0.1	0.1	0.3	0.1	---	---	---
18	2	---	---	---	---	---	---	---	---	---	---	---	---
Total	626	3.9	13.3	0.3	1.0	1.0	4.5	1.7	5.2	3.1	6.0	---	0.7

a/Mean height above-ground less than 2 in.; does not include injuries below-ground.
b/Mean height above-ground at least 2 in.
c/Includes wounds 'at least 7 in. wide'.
d/Estimated by multiplying maximum vertical wound length by maximum horizontal wound width.

Table 4.— Numbers of stems wounded or destroyed by feller/buncher activity at Watersmeet Block C, and frequency with which selected criteria of wound severity were met, expressed as per cent of residual stocking by diameter class

dbh class (inches)	Residual stocking	Stem count (per acre)											
		Wounded or destroyed		Wound at least 7 in. wide		Wound at least 4 in. wide[c]		Wound LxW at least 50 sq. in.[d]		Wood penetrated or gouged		Broken top	Destroyed
		Roots[a]	Stems[b]	Roots	Stems	Roots	Stems	Roots	Stems	Roots	Stems		
2	70	---	1.3	---	---	---	---	---	---	---	0.4	---	0.8
4	194	0.9	9.8	---	---	0.1	0.8	---	1.2	0.1	2.8	0.1	2.3
6	114	1.9	8.0	---	0.1	0.1	1.3	0.1	1.7	0.1	3.2	---	0.1
8	82	2.2	9.7	---	0.8	---	3.0	0.1	3.2	0.1	4.6	---	0.1
10	46	2.1	7.9	---	0.5	0.1	1.8	0.3	1.9	0.1	3.0	---	---
12	13	0.9	1.9	---	0.1	0.1	1.2	0.1	1.0	---	0.9	---	---
14	6	0.5	0.8	---	0.1	---	0.5	---	0.5	---	---	---	---
16	2	0.4	0.8	---	0.1	---	0.5	0.1	0.4	---	0.1	---	---
18	0	0.3	0.3	---	---	---	0.1	---	0.1	---	---	---	---
Total	527	9.2	40.5	---	1.7	0.4	9.2	0.7	10.0	0.4	15.0	0.1	3.3

a/Mean height above-ground less than 2 in.; does not include injuries below-ground.
b/Mean height above-ground at least 2 in.
c/Includes wounds 'at least 7 in. wide'.
d/Estimated by multiplying maximum vertical wound length by maximum horizontal wound width.

Table 5.— Numbers of stems wounded or destroyed by feller/buncher activity at Spooner, and frequency with which selected criteria of wound severity were met, expressed as per cent of residual stocking by diameter class

dbh class (inches)	Residual stocking	Stem count (per acre)											
		Wounded or destroyed		Wound at least 7 in. wide		Wound at least 4 in. wide[c]		Wound LxW at least 50 sq. in.[d]		Wood penetrated or gouged		Broken top	Destroyed
		Roots[a]	Stems[b]	Roots	Stems	Roots	Stems	Roots	Stems	Roots	Stems		
2	191	0.4	30.7	---	1.1	---	1.1	---	2.9	---	0.4	7.1	15.7
4	229	0.7	47.1	---	3.2	---	11.4	---	18.6	0.4	4.3	7.1	9.3
6	108	1.1	32.5	---	6.8	---	20.0	0.4	18.6	0.4	6.4	3.2	1.4
8	116	2.5	32.5	1.1	1.4	1.1	24.3	1.8	24.3	0.4	10.7	0.7	---
10	66	2.1	25.7	0.4	1.2	1.1	21.8	0.4	21.8	---	8.6	0.4	---
12	19	2.5	11.1	0.4	7.5	0.7	10.7	1.1	10.4	0.7	4.3	---	---
14	4	0.4	2.1	0.4	1.8	0.4	1.8	0.4	1.8	---	0.4	---	---
16	1	---	1.1	---	0.7	---	1.1	---	1.1	---	0.4	---	---
18	---	---	---	---	---	---	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---	---	---	---	---	---	---
22	---	---	0.4	---	---	---	0.4	---	---	---	---	---	---
Total	734	9.7	183.2	2.3	45.7	3.3	92.6	4.1	99.5	1.9	35.5	18.5	26.4

a/Mean height above-ground less than 2 in.; does not include injuries below-ground.
b/Mean height above-ground at least 2 in.
c/Includes wounds 'at least 7 in. wide'.
d/Estimated by multiplying maximum vertical wound length by maximum horizontal wound width.

DISCUSSION

The greater the residual basal area, given comparable diameter distribution, the more difficult it will be for a feller/buncher operator to remove marked stems without damaging the residual stand. Likewise, the greater the distance the feller/buncher must travel within the stand between established trails the greater will be the potential for damage to the residual stand. In order to minimize damage to the residual stand, harvesting equipment should be selected to maximize maneuverability and minimize machine size. Further, reduction of basal area to the lowest residual figure consistent with sound silviculture should also reduce damage by opening up the stand and allowing the harvesting equipment to maneuver as efficiently as possible.

The marking guidelines adopted must take into consideration the operating characteristics of the harvesting equipment to be used. The Watersmeet study site was originally marked for conventional chainsaw thinning, but was subsequently thinned mechanically without being re-marked. Feller/bunchers can not be expected to operate as deftly among the residual stems as a manually operated chainsaw. In particular, a feller/buncher can not be expected to remove individual stems from sprout clumps without

severely damaging residual sprout partners. Also, when deciding on the width of residual blocks for a strip thinning with selection between strips, it is important to know what kind of feller/buncher will be used. The residual blocks in the Spooner study were too wide for the Timco Hydro-Buncher to reach all marked trees between adjacent strips. As a result, either the center of each residual block will remain un-thinned, or a second thinning (causing additional damage) will be conducted to remove marked stems from the interiors of the residual blocks.

Other guidelines for reducing damage include 1) marking crop trees so that they will be easier to avoid, 2) restricting the logging season, and 3) leaving 'bump' trees as buffers along the edges of skid trails (Aho et al. 1983). Bark is looser during the spring and early summer; logging during this period results in more and larger wounds. Damage might have been significantly less severe on Watersmeet Blocks A and B and at Spooner if logging had been conducted later in the season. Conversely, damage to Watersmeet Block C might have been still more severe had that block been logged earlier in the season, as were Blocks A and B. 'Bump' trees, left along the edges of skid trails, protect the residual stems and should be removed last of all.

Wound dimensions probably should not be measured earlier than the second growing season following injury, especially on yellow birch. Yellow birch wounds have been shown to enlarge an average of 3.7 in. vertically and 1.2 in. horizontally over the 20 months following injury (Benzie et al. 1963). Sugar maple wounds enlarged little. In addition, bruising of birch stems can cause cambial death and eventual sloughing of the dead bark. Injury enlargement has not yet been measured in either the Watersmeet or the Spooner study.

Tree species also differ in the rate of defect development in response to various kinds of wounds. In a study of skidding wounds on yellow birch and sugar maple, root wounds did not cause direct loss of sugar maple log or lumber value; however, root wounds caused nine per cent of the yellow birch lumber value loss (Ohman 1970). Yellow birch root wounds leading to lumber value loss in 10 years 1) had maximum wound length times width (LxW) of 50 sq. in. or greater, 2) reached within four feet of the bole, and/or 3) were in contact with mineral soil. In both species, about two-thirds of all stem wounds leading to lumber value loss after 10 years had LxW of 50 sq. in. or greater.

No attempt is made to anticipate the significance of individual logging wounds to future stem quality. Total numbers of injuries recorded certainly involve some trees which would not have become sawtimber crop trees even had they not been injured, as well as some wounds which will not result in sufficient decay/discoloration to reduce log or lumber values. There is no way to know whether a particular tree was injured 1) solely because of its position in the residual stand relative to marked stems and feller/buncher operating characteristics, or 2) partially because

the equipment operator made a conscious choice at the time and decided that the stem to be injured had less potential to become a sawtimber crop tree than a neighboring stem which was spared. In most cases, however, feller/buncher and skidder operators do not have the time or the expertise to consider the implications of damaging one stem rather than another. Furthermore, there is often no motivation for operators to minimize logging damage; the financial incentive is simply to complete the harvest as quickly as possible. It would be a mistake to forget that operator pride and skill are as important for minimizing logging damage as any of the other technical considerations mentioned above.

Earlier studies of wound/decay relationships have used trees of large pole or sawtimber size, which might soon be harvested. The Spooner and Watersmeet studies considered injury to smaller size classes as well, which nevertheless will provide the sawtimber crop trees of the future. Concern for smaller diameter classes is justified if foresters are to have the maximum freedom to designate the sawtimber crop trees of the future. Ohman (1970) found that only 20 wounds (all less than one inch wide) of the 239 wounds studied, healed in 10 years. Sapling and pole-size stems may not reach sawtimber size for 20 years or more. Relatively small wounds on young trees may result in considerable defect by harvest age or in early removal. Lavallee and Lortie (1968) found that infected yellow birch wounds 20 years of age or older were severely decayed, with the associated decay columns extending between 3 and 5 times the wound length. As damage to residual stems increases, value of the average crop tree may decline, and the professional forester may find it necessary to disqualify potential crop trees due to logging injury.

Clearly, lower quality stems or stands will suffer less value loss due to a given level of damage than will similar higher quality stands. Likewise, stands to be harvested for fiber will lose less value due to a given level of damage than will similar stands to be harvested for sawtimber.

CONCLUSIONS AND RECOMMENDATIONS

A standardized approach to the study of logging damage is needed in order to systematically evaluate the effects of alternative harvesting systems on residual stem quality. Planning for the damage study should be as thorough as planning for study of the harvest itself; comparison of alternative harvesting systems is possible only if it is planned for in the overall study design.

Logging damage is apparently directly related to residual basal area. As residual basal area increases, given similar diameter distribution, there are more targets for injury, and maneuverability between stems becomes increasingly difficult. Logging damage can be reduced by leaving the smallest acceptable residual basal area. It follows that smaller, more maneuverable equipment should cause the least damage, other factors being equal. Damage

can also be held to a minimum by avoiding mechanized thinning in the spring and early summer, by marking stands with full knowledge of the equipment to be used, by increasing the skills and pride of equipment operators, by using 'bump' trees along paths of equipment travel, and by marking crop trees so that they can be consciously avoided.

More injuries are generally created than are noted. Smaller injuries and injuries to smaller stems are often ignored. Under the selection system of managing northern hardwoods, however, injuries to smaller stems may result in early harvest or in development of significant defect by harvest age. In either case, the forester will have fewer high quality stems from which to select crop trees. Destruction of smaller stems during thinning also reduces the forester's choice of crop trees. Of course, logging damage is much less important if the stand is ultimately harvested solely for fiber. The importance of logging damage also depends on the potential quality of the residual stand before logging damage. The poorer the original stem quality in the residual stand, the less impact a given level of damage will have on stand value.

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IMPACT OF HARVESTING TO THE SOIL

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Abstract.--Disturbances of the soil often result in compaction and erosion. Studies have shown that compaction may persist for many years following disturbance, resulting in altered soil moisture, soil aeration and soil strength regimes. These effects have been demonstrated to reduce forest growth. A study in northern Wisconsin found a 200 percent increase in bulk density of the surface soil following mechanized thinning operations. A controlled loading test with a forwarder also demonstrated a significant increase in bulk density which was not related to loading weights. These studies conclude that compaction results with the first few passes of a vehicle.

Mechanical disturbances of the soil often affect its condition by altering its structure as a result of compaction, puddling or erosion. Mechanical soil disturbances in a typical northern hardwood thinning system are most typically caused by felling, skidding, forwarding and decking operations. Often soil disturbances are not regarded as having any detrimental effect on the site. However, recent research has demonstrated that soil disturbance can have significant long term impacts on the site. Potential impacts of soil disturbance include: reduced productivity, poor seedling survival, nutrient loss, increased erodability, impaired trafficability and alterations in species composition.

It is the objective of this paper to present an overview of the potential effects of soil disturbance resulting from harvesting, and especially those effects associated with northern hardwood thinning systems. Factors affecting soil disturbance, conditions resulting from soil disturbance and effects of disturbance will be reviewed. A regionally important study on soil compaction resulting from mechanized thinning systems[2/] will also be discussed.

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2/Padley, E.A., S.G. Shetron, C.C. Trettin. Soil Compaction Produced by Thinning Pole Sized Northern Red Oak Stand. Final Project Report - U.S.F.S. - 23-81-50. Michigan Technological University.

DISCUSSION

Soil Compaction

Compaction is the most significant effect resulting from mechanical disturbance of the soil. The direct effects of soil compaction are on the soil moisture regime, soil aeration and soil strength. Alterations of these properties can have significant effects on the residual stand as well as subsequent regeneration.

Compaction is affected by inherent soil and site factors, and by harvesting factors. The soil and site factors which have the most significant influence on compaction are a) texture, b) organic matter content, c) moisture content, d) litter thickness, e) soil structure (Alexander, 1980; Howard, 1981; De Kimpe et al., 1982). The degree of soil compaction has been shown to correspond with the field moisture state (Moehring et al., 1970, Sidle and Drlica, 1981, DeKimpe et al., 1982). Generally, susceptibility to compaction is highest at a moisture content of 60-100 percent of the water holding capacity of the soil. Therefore, it follows that wet, fine textured soils are more susceptible to compaction than dry, coarse textured soils.

The slope and relief of the site also have an influence on the degree of soil disturbance. Generally, as the slope and micro-relief increase the extent of disturbance will increase. Logging methods and types of logging vehicles will also have a bearing on the extent of soil damage. The volume of timber removed will also have an influence; the greater the cut volume the increased number of vehicle pasess required to remove the timber. Correspondingly, Hatchell et al. (1970) found that bulk densities were 52% greater on the log deck, 40% greater on primary skid trails and 23% greater on secondary skid trails, when compared to control plots. Similar increases in soil strength were also demonstrated, while infiltration rates were reduced 89% on log decks, 87% on primary skid trails and 78% on secondary skid trails over the control plots.

The effects of soil compaction on tree growth have been documented. Youngberg (1959) found a 78% increase in bulk density on skid trails versus undisturbed soil and a correspondingly significant difference in height growth rates of planted Douglas-fir (Pseudotsuga menziesii) on trails and undisturbed areas. Sixteen years after logging, Froehlich (1979) demonstrated a 12% reduction in incremental growth rates of ponderosa pine (Pinus ponderosa Laws.) growing in areas which had an 18% increase in bulk density, when compared to undisturbed areas. Went and Thomas (1981) evaluated the growth response of douglas fir to soil compaction, 32 years after logging. They found significant differences in bulk density when comparing skid trails to undisturbed areas. Growth measurements indicated a reduction in volume and density on skid trails when compared to undisturbed areas.

Although no growth studies exist which pertain to the lake states region, it may be inferred from other studies that there is justifiable concern for potential growth reductions associated with soil compaction. Russell (1973) reports that roots will rarely penetrate light-textured soil if its bulk density exceeds 1.7 gm/cc or a heavy textured soil if it exceeds 1.5 gm/cc. The factors associated with increased bulk densities which may

limit plant growth are reductions in moisture holding capacity and aeration, and increased resistance to root penetration.

Compaction of soils has been shown to persist for more than 15 years following logging (Froelich, 1979; Went and Thomas, 1981). Additionally, Hatchell (1970) demonstrated that one vehicle pass can cause as much damage as several passes on moist, medium textured soils. He also suggested that effects associated with compaction may be ameliorated through loosening and revegetation or mulching the disturbed area.

Soil Erosion

Soil erosion in forests is typically associated with logging operations and road construction. The erosion is caused by exposure of the mineral soil surface, disturbance of the subsoil and soil compaction (Pritchett, 1978). The extent of the erosion hazard is dependent on the degree of disturbance, but is typically most severe on skid trails and log decks and in other areas which have had the subsoil disturbed. Rice et al. (1972) reported that 16% of the harvested area had bare soil after selection logging with a tractor. Areas which have been severely disturbed should be remedied to minimize the erosion hazard. Other areas will typically revegetate naturally following the disturbance, controlling the erosion hazard.

Soil Compaction in the Lake States

A study was conducted in northern Wisconsin to assess soil compaction resulting from mechanized thinning of a northern red oak (Quercus rubra L.) stand. The thinning system was the strip selection method (Biltonen et al. 1976), which consisted of felling with a Timbco Hydro-Buncher and skidding with a John Deere 640 grapple skidder. The study area was characterized by a pole sized red oak stand occurring on a loamy glacial till soil (Typic Eutroboralf, coarse-loamy, mixed).

Three skidding strips were randomly selected. The strips were then divided at a point midway between the first and last cycle made by the grapple skidder, thereby identifying high use versus low use areas on the strips. The high use area had a mean of 12 vehicle passes compared to 6 for the low use area. The high and low use areas were subdivided into compartments for sampling. Bulk density was determined for the 0-5 cm soil layer using the modified excavation method (Bradford and Grossman, 1982). Three sampling periods were utilized; immediately following harvest, 3 months and 12 months after harvest. A control area was located adjacent to the harvested stand.

Results of this study indicate that there is a significant increase in bulk density of both the low use and high use areas when compared to the control, during each of the sampling periods, Table 1. There was no significant difference in bulk density between the high use and low use areas. Analysis of bulk densities between sampling periods demonstrated no significant changes in the treatment or control areas over the 12 month sampling period.

Table 1.--Mean air dry bulk densities by treatment area and sampling period

Treatment	Sampling Period		
	June, 1982	Sept., 1982	July, 1983
	Bulk Density (g/cc)		
High Use	0.80a[3/]	0.78a	0.75a
Low Use	0.77a	0.79a	0.79a
Control	0.42b	0.45b	0.44b

3/Where 'a' is significantly different from 'b' at the 95% confidence interval and no difference between 'a' or 'b'.

The results of the bulk density analysis indicte that increases in soil strength occur with the first few passes of logging equipment and that the compaction is not mitigated within twelve months of the disturbance. The moisture content of the soil was near field capacity during the time of logging. Howard et al. (1981) found that the maximum compactability of soils occurs at moisture levels near field capacity. This indicates that logging was conducted at the soil moisture content which most affected soil strength.

A comparison study was conducted at the same time to assess the effects on compaction by a forwarder (Gafner Iron Mule) under controlled loading conditions. The forwarder had three loading conditions: empty, half load and full load. Under each loading range, 4 and 12 passes were made over an undisturbed soil area. Bulk densities were determined for the 0-5 cm soil layer within sampling compartments.

Results of this study indicate that each of the treatments significantly increased bulk density when compared to the control area, Table 2. There were no significant differences between treatments. These data indicate that soil strength is affected by the first few passes of the vehicle and that the loading rate does not significantly contribute to the degree of compaction caused by this vehicle. This trial was also conducted at a soil moisture content near field capacity, which results in the greatest increases in soil bulk density (Howard et al., 1981).

Table 2.--Mean bulk densities by treatment for the controlled loading trail, following treatment.

Treatment	Bulk Density ----g/cc----
Empty, 4 passes	0.91a[4/]
Empty, 12 passes	0.85a
Half load, 4 passes	0.84a
Half load, 12 passes	1.00a
Full load, 4 passes	0.85a
Full load, 12 passes	0.80a
Control	0.47b

4/Where 'a' is significantly different from 'b' at the 95% confidence interval.

CONCLUSION

Soil compaction has a direct effect on soil moisture regimes, soil aeration and soil strength. Changes in these properties may have a significant effect on the residual stand as well as on regeneration. Recent research conducted in the Lake States supports studies conducted in other regions which indicate that: a) soil compaction occurs with the first few passes of a vehicle and that compaction readily occurs at moisture contents near field capacity, and b) compaction is not mitigated over short time periods.

Management operations on unevenaged stands should be designed to concentrate disturbances on the smallest practical area in order to minimize the extent of soil damage. Harvesting operations should be scheduled during periods of low soil moisture and curtailed, if possible, during saturated soil conditions. Soil interpretation guides for harvest scheduling have been prepared by the Soil Conservation Service for northern Michigan and may be utilized to plan harvesting operations to minimize disturbance on soils of different types.

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HARDWOOD OPPORTUNITIES UTILIZING THE PACK-A-BACK SYSTEM

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Abstract.--Presents Owens-Illinois, Inc. philosophy of timber harvesting in Northern Wisconsin and the Upper Peninsula of Michigan. With emphasis on the evironment, economics and utilization, tree length logging using pole skidders is compared with shortwood pack-a-back systems. The paper concludes the pack-a-back system is superior to all the criteria examined when compared with tree length pole skidding.

Owens-Illinois owns 264,000 acres of fee lands in Northern Wisconsin and the Upper Peninsula of Michigan, of which 112,000 acres are intensely managed northern hardwoods. As stewards of these lands, our professional foresters manage all of our lands to insure that we have a continuing forest crop available for harvest that insures the corporation of it greatest return on investment. With that in mind, we have adopted a logging system that meets these criteria for all of our forest lands.

In contrast to our competition in the Lake States, with the over constructed, over engineered, oversized and over financed harvesting systems, we at the Tomahawk operation prefer to merchandise at the stump by using training, recognition, and incentive programs for our professional timber workers. Through many trials and efforts, we have found the most efficient and productive system to be the pack-a-back system. We use the term "merchandising at the stump" in which our professional timber workers fell and buck the highest grade sawlogs, bolts, and pulpwood. Our utilization standards are second to none. We encourage our timber workers to buck up all products down to a one-inch top. In our present company operation, we have 50+ different sorts and products and deliver forest products to 21 different mills in the Upper Peninsula and Wisconsin.

In our selective harvesting in northern hardwoods, by using the pack-a-back system we find little or no damage to the residual stand, less compaction to the soil, minimal damage to the root system, reduction in road construction, and much smaller landings.

One real advantage we find in products forwarded roadside by the pack-a-back system, is a cleaner product for both sawmills and the paper mills. Pole skidded wood, cut especially in certain sandy sites, is heavily embedded with sand which is abrasive to debarking and pulpmill systems and adds to the contamination of our waste water system. Pole skidding systems are very sensitive to trucking and significant time is spent in building landings which also reduces our land base for growing forest products. Production with the pole skidding is very sensitive to trucking and has a very limited efficiency for sorting high-value products.

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[1]Operations Manager, Owens-Illinois, Tomahawk Wisconsin.

Fuel savings are very obvious. A 4500 Series Iron Mule will consume about 5 gallons of fuel a day to skid 30 cords roadside. With the pole skidding system, one gallon per cord is consumed. This is based on the average 300-foot skid. It has been our experience that during the summer months, a timber worker using a pole skidder uses up a power saw chain about every 8 days and a new bar every 4 chains. The expected life of a chain saw is six months or less vs. the system we are presently using wherein a chain saw lasts up to three years. Our best timber worker under this system uses one bar and four chains each year.

Those of you that insist on using mechanized systems in harvesting northern hardwoods because of high compensation rates or because labor is not available, I say to you, this is a cop-out. With record unemployment rates in northern Wisconsin and the Upper Peninsula, with training, recognition, and incentives, I am sure we can obtain the labor necessary to harvest our forests.

For those of you that maintain that under this system you will incur high workers' compensation rates because of accidents, I might point out to you that as of March 15, 1984, our Northern Woodlands harvesting crew recorded 349 working days without a lost time accident. Our professional timber workers are required to wear hard hats, eye protection, hearing protection, leg protection, and safety toe foot apparel. All power saws are equipped with safety chains and chain brakes, and every timber worker is involved in a safety discussion with his immediate supervisor every two weeks.

In summary, the advantages of this system are:

A. Improved sorting of high-value products.

B. Less damage to residual stands.

C. Less soil compaction.

D. Longer skidding distances.

E. Cleaner forest products.

F. Less fuel consumed.

G. Less landing room.

H. Truckers preferance to pack-a-back piles wood vs. pole skidded which often includes many doubles.

I. Overall, leaving the stand aesthetically pleasing to the general public.

LOGGER'S PERSPECTIVE OF THINNING HARDWOODS

Marvin Roberts[1]

Abstract.--A practical, common sense approach to commercially thin hardwood stands is presented. The proper equipment, the right people, a good job of marking trees, correct job layout and planning enables the logger to reduce logging costs.

Thinning--selective logging--and uneven-aged management, three ways to say the same thing, and the only way to profitably manage northern hardwoods.

The fastest way to get many of our present hardwood stands to the point where it is profitable for the land holder to grow trees is through a series of thinnings. The logger that performs these thinnings, successfully, is a specialist and therefore many of his problems are unique. Before I get into these problems and some possible solutions, I would like to make a statement of fact which I believe to be absolutely necessary for any thinning operation.

All of the people involved--land holders, foresters, cutters, skidder operators, and managers--must know and understand the immediate and the long term goals of uneven-aged forest management. These goals must remain constant.

The methods of attaining these goals will vary with loggers, terrain, weather, markets and time, but the goals should not change. They are the stabilizing point in a very unstable business. It is like trying to run a race in which the position of the finish line keeps changing. You have to establish goals and then stay with them. It is very easy to lose sight of the long term goals when dealing with the everyday problems. There is a strong tendency to "go with the flow." This might be easy for awhile but the "flow" usually ends up in a waste treatment plant and our hardwood stands deserve better. Thinning means "planning for the future."

Recreational use of the forest is an actuality and must be recognized as such. When these forest visitors come around to see what you are doing, thinning is much easier to defend than any other type of logging. In most cases you won't have to defend thinning. The aesthetics of thinning make it the most attractive way to log. It might even prevent a burned skidder or other acts of vandalism.

Since uneven-aged management is a series of thinnings, it means that the re-entry periods are relatively short, usually in the 5 to 10 year time frame.

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[1]District Land Manager, Champion International, Wakefield, Michigan.

This may allow the same logger to re-log or re-thin the same area several times in his life time. This will enable him to get familiar with all of the pecularities of the area. For example, where the timber is at, where to log in wet weather, skid trail and road locations, availability of gravel and whatever. All of these things should increase the efficiency of the logging operation.

After the initial thinning, the following loggers should be able to utilize the roads and landings used by the first logger. This has to be a large saving for them. Also, by reusing the same road every 5 to 10 years, the roads should remain in a useable condition. Each successive use of the road will tend to up-grade it and at minimal cost.

Each successive thinning should produce higher valued products. So the biggest problem is to make that initial thinning of a stand that yields only pulpwood or firewood. One of the more practical ways to accomplish this is to include a previously thinned or good patch of timber with each un-thinned tract. This will effectively spread the total logging costs over a larger volume and reduce the per unit logging cost. It will also result in a higher realiziation per average unit.

Another way to enable a logger to operate these initial cuts is to put up large timber sales with a lot of small blocks. Then don't require a lot of up-front money. Money is very expensive. A lot of blocks will enable the logger to better plan his work. This will give him the ability to cope with the changing markets and weather. This type of logger is generally very mobile and versatile and will log every day that the weather permits. With the marginal profits on these initial cuts he has to.

It takes special equipment to economically thin hardwoods. This is most evident in the early thinnings. The logger must be properly equipped for the job. You don't thin carrots with a D-8 Cat if the long term goal is to raise and harvest carrots. The proper equipment will vary with the logger and with the job to be done. Without going into the pros and cons of the various types of equipment, in thinning, the space to operate equipment is always limited. So, the general rule is--stay light, stay small, and stay mobile.

Also, I wish that foresters and managers would expect and demand the same end result from all loggers. Don't let logging equipment become an excuse for poor logging practices. This is not fair to the concientious logger. Good loggers just want to be treated fairly. They are not looking for a subsidy nor can they afford for their competition to be subsidized.

Some people enjoy doing quality work. They are quality rather than quantity oriented. They like to see the good results of their efforts. Stand improvement by thinning provides that opportunity. In most cases, results are apparent in relatively short periods of time. This can be very rewarding to quality type people. People do the thinning.

It is highly unlikely that you will be able to erase years of poor logging and mismanagement practices with one thinning cut. So when you mark a hardwood stand, please keep these two thoughts in mind. One--this is the first of a series of cuts. Second--marking will always be a compromise between economics and silviculture.

The first time a stand is marked can and should set the pattern for skid trails. The way the stand is marked dictates to a large degree what kind of equipment can be used to cut and skid. For example, if you are marking for a feller-buncher, you have to leave sufficient room to operate the machines. Once these skid trails are established, and if they are in the correct place, they will probably be used again and again in the successive thinnings.

In marking, don't be tight with the paint on each tree. Looking for paint wastes time. The ideal way to mark is with a paint "ring" around each tree. I personally believe that the "ring" is worth the extra paint and effort. The "ring" marking also enables the marker to better control his spacing etc.

The marker should be knowledgeable and practical. If trees are marked in a soft area, expect the skidder to leave ruts. If a large tree surrounded by saplings is marked, expect a lot of saplings to be damaged. If scattered trees are marked in thin areas, expect some trees to be left. It is not what is left that hurts, it is what is cut that does. Don't expect the impossible, but insist on the possible.

Don't get hung up on minimum volumes per acre. There are too many variables in the efficiency of loggers and in the thinning job. Ground conditions, haul distances and the season of operability, just to name a few. Recently, I saw an 80-acre hardwood tract that yielded two cords and 450 Bft per acre. The logger did a very good job of thinning with a minimal amount of logging damage and made money logging.

The bottom line for marking is--it takes a good job of marking to enable the logger to do a good job of thinning.

IN SUMMATION

Marking will always be a compromise between economics and silviculture. Operating space for cutting and skidding will always be limited. Quality people will do a quality job of thinning. Don't get hung up on minimum volumes per acre. Uneven-aged management means a series of thinnings, so some times it might be more practical to wait until the next cut to do or not do a certain thing. Don't keep changing the goals. Uneven-aged management is real. It is attainable! It does require a commitment to the future.

SESSION II - DISCUSSION

Q1. In managing hardwood stands, preparing timber sales and contracts, and working with the logger to help meet our silvicultural goals, some large culls or poorly developed trees are always left that no one would consider cutting. We then go back and deaden those trees with an ax, a chain saw, or whatever. My question is that if this is labor intensive and expensive, is there any research or development in progress on a better way to do it?

(Moderator Abramson) Dick, would you address that from Owens-Illinois' point of view?

A1. (Bierlich) I suggest that the operations people in the woodlands department insist that the mill use the fiber that is available. Pulp is residue, and I totally believe that. The paper mill superintendent cannot tell if chips come from veneer logs or twigs. Often when I walk into the woodsroom, I find the woodroom operator sitting there with nothing to do. They are worried about doubles, forks, and everything else. We should put them to work! We have the technology to use the fiber. This is the answer as far as I am concerned or our corporation is concerned. I have total backing from top management on it. Some days when our wood supply is low, we do not even bother to delimb because we have to move some fiber, and it all makes fiber.

(Moderator Abramson) John, would you comment on that from the engineering research point of view?

(Sturos) As far as I know, no one has researched removing cull trees as such. This has been identified as a problem in the South also. One thing we have looked at is trying to recover fiber from large hardwood sawlog tops--looking at various residue recovery methods. We designed, fabricated, and tested a "topwood harvester" to snip the large limbs of the topwood and bunch them in the bunk of the harvester with the major stem of the top and forward them to roadside. We have collected productivity and cost data on this type of residue recovery operation. We have not studied recovering standing cull trees which should be researched. It would depend on its priority compared to other land management problems.

(Johnson) Initially in our stands we had a sizable number of culls. The ones you are referring to fall apart--they are not even usable for firewood in most cases. We required that they be marked with an "X," cut, and be a part of the sale agreement. Some companies have allowed some adjustment on a per tree basis for felling those trees, and I believe that is the best way to handle the situation. When the contractor is logging, we should give him some incentive--reduction in stumpage, etc.--to remove those trees because some cost is borne in the process.

(Moderator Abramson) One thing we have to keep in mind is the regionality of some of the markets. There may be cases where it is reasonable to require that the trees be cut, removed, and marketed, and there may be

other areas where the hardwood market is so poor and so distant that no matter what requirements you put on the logger, you are going to have trouble getting them to fell or do anything but deaden the trees. There is a certain amount of reasonability that has to be kept in mind.

Q2. In places where there are good saplings and poles underneath the large cull trees, is it better to leave these trees standing rather than cut them down and possibly do extensive damage?

A2. (Erdmann) I think that at some point in time we have to address the question of removing culls. I am in favor of that, except for those that should be left for wildlife habitat. We should decide that first. Leaving a dead tree standing is not going to hurt anything, when it comes down piecemeal. But if you have too many culls in the stand, I would surely drop them and treat those areas so they can produce quality trees. Under uneven-aged management, the cull will take as much space as one of the 53 sawlog trees. It is important to address that situation initially when you enter those stands--drop them now, accept the damage, and mark any poor quality tree that is in that "hole." What we want to develop is the seedling regeneration. There often is a poor quality sugar maple, and at that time, it should be taken out. That is the only thing that we really differ from what Eyre and Zillgit (1953) and Tubbs (1973) have reported; when we make a hole in the stand by removing a large, sawlog-size tree or cull tree, we will do a little TSI job on it at that point. It amounts to only four or five spots like that per acre. On the Argonne Experimental Forest, we mark those trees, and they take them out with the cut at no actual cost to us. Even dead trees, such as dead elm from Dutch elm disease, we mark as dead, and they harvest them for pulpwood if they can use them.

Q3. Damage keeps coming up over and over again. Has any work been done looking particularly at limiting skidding during the slippery bark season?

A3. (Erdmann) I think that is very important. What we would like to do is do all our logging on frozen ground. It limits stem and root damage. In some areas of the U.P., you cannot do that because you really do not get frozen ground, so some of it has to be done. I would say that we would like to do most of our logging in frozen ground conditions. We want no damage on the Argonne Experimental Forest. We have had the third and fourth cuts in our NH-25 cutting method study. We have had almost no damage in the third cut; in the fourth cut, we used Iron Mules and had no root or bole damage. We do hold them to working in frozen ground conditions. We get a little rutting on a few days, but usually they will shut themselves down. A lot of our good work done on the Forest is due to our Forestry Superintendent; he does a very good job of logging supervision. The foresters have to go out and talk to the loggers when unacceptable damage occurs. It is important to have logging supervision and train your operators not to damage trees.

Q4. I have a question that deals with the Spooner case study site. The Spooner site was cut in two different time periods--in the fall and then also with the Timbco in early summer or spring. In the fall cut there was very little visual damage. However, in the spring cut, we had a

significant problem. When you examined damage on that site, did you identify which area was cut in the fall and which was cut in the spring?

(Moderator Abramson) On the Spooner study, is there a difference in damage noted in the areas that were cut in the fall versus the spring?

A4. (Bruhn) I would not say that my study was an afterthought, but I came in after the logging was actually done. John Sturos tells me that I inventoried only on the spring cut.

(Sturos) No comparison was done on that. However, I am sure we could glean something from that comparison and will make every effort to do it.

(Erdmann) For a first thinning in a stand, strip thinning with selection between the 10-foot-wide strips looks like a good treatment from what I have seen. Enough of the initial stand basal area should be removed. You have to get down to about 65 square feet, so you will not damage the good quality, residual trees. In that way you can use mechanized thinning for uneven-aged management. Preparatory to setting up a shelterwood, you can use mechanized thinning and then also take off the shelterwood overstory with bigger equipment, except for what I heard earlier about compaction. It looks like another good option to use big equipment in these stands. There are several good opportunities to use some mechanization in these thinnings.

(Moderator Abramson) Thanks, Gus. Dick, would you comment on restricting logging from an industrial point of view? We seem to be saying that in many higher quality stands, we want to restrict logging to, in one instance, the winter season only.

(Bierlich) We run our crews year round. We are especially cautious during the May and June period. I would not go into a first thinning stand, but we go where we have log diameter trees, etc. and watch our skidder operators. You cannot expect him to pay $50-to $60,000 for equipment and operate it for only 6 months of the year. You must watch his training programs, your stands, and your markings. As Mr. Roberts stated earlier, you must mark your timber to fell it and skid it. You cannot totally restrict the man; he has to operate unless you go back to horses. And they cause damage as Allan Fray's study indicates. We operate year round, and it requires supervision and training in the stand. You must watch the stand you are working in.

(Roberts) I would like to add one thing. One of the main reasons the forest industry is so attractive in Michigan's Upper Peninsula is because we have such a high unemployment rate. Equipment dealers have to make a living, but let us put the people to work, too. People do not tear up the trees; it is the equipment that tears up the trees. One of the panelists just mentioned that 80 percent of all damage was from backing equipment into the trees. If this is so, damage could be reduced if operators were better trained in extension courses.

(Moderator Abramson) Carl Trettin, would you comment on season of logging versus damage in some of these stands?

(Trettin) The critical thing illustrated in a table that we showed--and most of it is common sense--is the seasonal wetness problems that occur on the soils. Naturally, springtime is the worst, during spring breakup and immediately after. If a soil has a tendency for a perched water table or has an inherently high water table, conditions can also be bad during other times of the year.

(Bruhn) There is one other component of damage that I will not even talk about except to mention that we do not know much about it. When you log in the spring, there is no way to evaluate what damage, if any, is done to the submerged root system. There has been no good method devised to study that; any effects on tree growth are hidden.

(Johnson) We have a study in progress; this year we remeasured root damage due to rutting that occurs during the wet season. We will evaluate that during this growing season.

(Erdmann) Some older research shows that as long as damage occurs more than 4 feet away from the bole, it is not likely transmitted to the main stem. I do not know what bearing that has on it, but that is the way we have looked at it. We have told our operators to stay away from the boles of the crop trees. We do not want them damaged at all. Thus far, we have done well with that on sugar maple in particular. That is the main species in most of our stands.

(Bierlich) Quite often when we get very wet periods, our crews will cut out roads. We cut all our roads out first; you can do a lot during extremely wet periods by doing that. The real goal is to make sure our people are employed year round and that we have a continuous supply of wood to the mills. We certainly have to use good judgment from our forest management people--emphasize training and lay the law down. We are not going to damage the boles. There is always a danger in root compaction. I thoroughly understand that. Skidding trails must be dispersed; allow them to make one trip over a trail and move around. That is why you have an Iron Mule going from stump to stump to stump. It offers a lot of versatility. It can be done; we have to do it. It is something we have to work with economically, but we can do it.

Q5. We have a question on the impact of bulk density on tree growth and also how significant this is at varying depths; was this looked at in some of the studies?

A5. (Trettin) Most of the questions raised have not been addressed in the Lake States which points to a gap in our knowledge. The bulk of the rooting mass for the tree species are in the upper portions of the soils. This phenomena can be seen to depths sometimes as much as 6 inches. In very sandy soils, we have seen, in essence, hardpans developed down 9 or 10 inches below the soil surface in areas where large machinery operated on them. In essence, what you have is a sieving action--big machinery sitting there vibrating, sieving out the fines. An artificial pan is created. The values that are critical to root development depend on the size of the roots and the species that you are dealing with. Generally, a bulk density of 1.3 to 1.7 grams per cubic centimeter can limit root

penetration. There is another phenomena associated with the bulk density and that is the root shearing, especially in the surface soils. In the Great Lakes region we have primarily very acid and infertile soil materials. All the nutrients are in the upper surface layer. By drastically disturbing it, you disturb the primary feeding area for the roots. In regard to your question on duration of bulk density, or how long it takes it to get back to a normal or steady state, work has been done. Probably the longest term studies have been conducted in the Pacific Northwest. There have been significant increases in bulk density as a result of machinery, persisting for up to 20 years. It is a very slow process. In the Lake States region where we have the freeze/thaw cycles, this may be ameliorated much more rapidly. Where we do not have soil freezing, it probably will persist longer.

Q6. Has anyone determined what percent of the area is impacted by the equipment in a normal skidding or logging operation?

A6. (Trettin) It depends on the methods of harvesting that are used on the sites. For the selection systems that we are speaking of around here, generally 30 to 35 percent of the area can be impacted. More intensive systems can go anywhere from 60 percent up to 90 percent in some of the real gross sites on clearcutting operations. It is a fairly large area.

What you are saying is that there is a 20 to 50 percent growth loss on 30 percent of the area.

(Trettin) That is correct.

Q7. In our part of the country the majority of the skidders are cable-type skidders, as much as 90 to 95 percent. Has there been any work done using that type of mechanized system--manually felling and skidding with a cable skidder using the strip cut/mark selection method?

A7. (Sturos) As far as I know, there has not been any. As I mentioned in my presentation, we evaluated the radio-controlled winch as a possibility. On the site where it was used, we had almost no damage with this particular semimechanized operation. We are now implementing a study on evaluating low-investment bunching systems to use in hardwood thinning. This certainly has the possibility of limiting the impact of the vehicle on the site. It has some possibilities in improving the overall picture, both economics and damage. Another point could be made. If we are talking of millions of acres that need to be thinned in this area at this time according to the figures Jack Spencer gave us in his presentation, another major concern is how we will get these 3 million acres thinned with the lower productive systems in time to take maximum advantage of what we have. Dr. Webster alluded to the fact that we now have the opportunity. Let us not let the status quo prevail. What can be done to take advantage of the opportunity the Lake States has at this point?

Q8. On ordinary marked sales on public land, the marker does not know what type of equipment will be used. Would you advocate preselecting the cutters for the first thinning or restricting the sale to specific equipment?

(Moderator Abramson) In the case of marking where you do not know the type of equipment that might be used, would you advocate tayloring the marking to the sale or preselecting operators depending on how you have marked a sale?

A8. (Erdmann) With the Forest Service, we have to take the low bidder. We restrict the size of the equipment. We had a restriction on our last cut that the equipment that would be used to do the skidding could be only 8 feet wide. That gives the size of the equipment that you want in the area to do the job and eliminates a lot of the damage.

(Sturos) This actually was the case in one of our case studies on the 1981 Watersmeet, Michigan thinning. That site was actually marked "selective" without any idea that it was going to be mechanically thinned. We had some difficulties there in running the operation. We experienced some inefficiency because the feller/buncher operators had difficulty determining what pattern to follow in this selective-type thinning. It also occurred in the skidding phase of the operation. We followed this study by implementing the 1982 red oak strip selection thinning near Spooner, Wisconsin where the feller/buncher path was predetermined by following the marked strips. This improved the operation considerably.

(Moderator Abramson) Taking into consideration who you are working for is part of the answer to that question. If you are in a situation such as most agencies or small private landowners that are putting their timber up for sale, they have to be concerned about who is going to log it and how the sale will be handled. Preselecting may be one of the answers, or as John said, put qualifications on the kind of equipment that can be used. In many industry cases, we already know who is going to log it before the stand is marked. We have a certain amount of control over who is going to be there, what type of operation he will run, and take that into account in doing the marking ahead of time.

(Bierlich) Too often we hear figures on mechanization that include 10, 11, or 12 cords per man-hour per machine and so forth. When you analyze the equipment, make sure you analyze and include all the mechanics, the foreman, the night mechanics, and the operators and equate them against the power saw man. Too often I have seen that when you go back to the Koehring-Waterous and Arbomatic systems and analyze the system, you find that the power saw man outperforms the mechanized systems in man-day production and man-year production. Everything must be taken into consideration. According to Waterous, it takes about three mechanics to back up their system per shift and about $150,000 worth of parts on hand at all times.

ECONOMICS OF THINNING FROM THE FOREST MANAGEMENT STANDPOINT

Dr. Gerald J. Thiede[1/]

Abstract --Hardwood management can and does pay. Precommercial thinning in hardwoods generally results in low rates of return. Careful selection of opportunities will improve the rates. Commercial thinning almost always improves returns, but at higher discount rates the quantity-quality relationships must be carefully analyzed.

HISTORY OF TSI ON STATE LANDS

To set the stage for the economic discussion to follow, I would like to list briefly the recent history of timber stand improvement (TSI) for northern hardwoods on state forest lands.

In fiscal 1974, the forest cultivation project, which funded a variety of intensive forest management practices, was initiated. In that first year, about 6800 acres were thinned either through reduced stumpage prices on merchantable trees, by direct payment to contractors or by using hired crews. The thinnings cost about $30.00 per acre. In fiscal 1975, 1976, and 1977, approximately 10,000 acres were thinned each year at a cost ranging from $34 to $39 per acre. In 1977 an interesting situation began to develop: costs began to decline. This was the year firewood markets began to expand and hardwood thinnings were becoming commercially valuable. This is well illustrated by the average cost per acre at Baraga versus those in the Cadillac area. At Baraga, thinning costs averaged $37 per acre compared to $16 per acre at Cadillac where a number of thinnings were accomplished at zero cost due to the firewood market. In the period from 1978 to 1984, thinning in northern hardwoods continued, with an increasing portion done commercially each year until nearly all such work was accomplished through timber sales.

As of today, nearly all the acreage of northern hardwoods considered suitable for precommercial thinning has been treated. The original objective of the program was to thin approximately 100,000 acres of the nearly 600,000 acres of northern hardwoods on state lands. The majority of the acreage thinned has a site index equal to or greater than 60. It was estimated that through careful selection of stands receiving treatment, an 8 to 12% rate of return could be achieved.

HARDWOOD MANAGEMENT -- CAN IT PAY?

Now I would like to take you through some case examples of hardwood management and explore the economic returns possible with precommercial and commercial thinnings. But first we need to consider all the assumptions that are used in this analysis. Most of the data used are based on DNR statistics. Others are reasonable estimates provided by knowledgeable people. Finally, some data are simply for illustrative purposes intended to help evaluate the impact of certain factors.

[1/]Planning Leader, Forest Management Division, Michigan Department of Natural Resources

The assumptions are as follows:

Forest land is purchased for $250 per acre, contains a pole timber stand of northern hardwoods which can be thinned, and is sold for $250 at the end of 50 years. A 50 year period is used for all the analyses. This allows enough time to reach similar timber harvests on a selection system regardless of the initial treatments. In the second table, no land purchase costs are included in the analysis. In certain cases land purchase costs are not appropriate. More will be said about this later.

Property taxes are $1.50 per acre per year. This is roughly correct for state lands and forest land entered under the Commercial Forest Act.

Administrative costs are $1.00 per acre per year, slightly higher than what is presently expended by the Department of Natural Resources.

Timber sale administration costs are computed at $1.35 per cord and $22.50 per thousand board foot for sawtimber. Precommercial thinning costs $53 per acre.

Commercial and precommercial thinnings do not result in increased timber volume harvests, rather an improvement in timber quality which is reflected in higher prices.

All costs and prices are in today's dollars and the analysis uses these values throughout except for the simulation of real price increases for stumpage. This means that the rates of return that are reported are real rates of return, i.e., rates of return above the inflation rate. To make them comparable to inflated rates of returns or the interest rate which one can presently get from the bank, credit union, etc., you must add the inflation rate to these rates. If the inflation rate is 6% and the real rate of return is 2%, then the inflated rate is approximately 8% (6+2) and that is what should be compared to bank interest rates. You will have to add the appropriate inflation rate to the internal rates of return (IRR) and to the discount rate for present net worth (PNW) listed in the tables in order to make comparisons to bank, credit union, or interest rates quoted when borrowing funds.

These are before tax IRR's.

Cutting is done on a 10 year cycle for a 50 year period. Stumpage prices for hardwood pulpwood are $4.50 per cord. Sawtimber stumpage starts at $45.00 per thousand board feet for the lower quality trees and increased to $100.00 per M. bd. ft. as thinnings are accomplished and quality improves.

Quite obviously as one changes the assumptions, rates of return will be affected. Although the values utilized in this analysis are fairly conservative, they should provide a fair approximation of what would actually be encountered in Northern Michigan.

ANALYSIS RESULTS

The results of the analysis under various assumptions are displayed in Tables 1 and 2. Before discussing those results, several additional points need elaboration. The question of whether timber can support a land purchase investment is of concern. There are situations where land purchase costs are appropriate to the analysis; others where it is not. If one goes out specifically to buy land or has bought land with the idea that the timber will support the investment, then the land purchase price is a legitimate cost. This is fairly straightforward. If a company buys the land and timber as insurance for mill supply, then the situation becomes more difficult. There are reasons other than an acceptable return on land and timber for the purchase. If the land is purchased for speculative reasons, i.e., for appreciation, then timber production returns should not bear the cost of land purchase. An individual buying land for recreational purposes should not measure all costs against timber returns. Public lands are owned for a number of reasons and provide a variety of outputs. Thus timber alone should not bear the costs of purchase. Because the inclusion of land purchase cost varies by situation and because it is a major expense, two analyses were done; one including land purchase and sale; the other assumes the land is already owned and retained.

The other major concern relates to real price increases for stumpage. The State of Michigan has experienced real price increases in softwood stumpage (this has leveled off recently with the increased supply due to budworm induced salvage offerings) and more recently for aspen stumpage. Hardwoods have not shown the same trend, but there has been little active competition for the overall hardwood resource relative to the large supplies available. As markets improve and competition increases, it is likely we will see some real price increases for hardwoods particularly considering the present low stumpage prices. Therefore, each table contains an analysis which includes a 1.5% real price increase for hardwood stumpage. This provides a reasonable basis for evaluating the impact of a real price increase on hardwood management returns.

As for economic criteria, both present net worth (PNW) and internal rate of return are utilized. In general PNW, which is discounted revenues minus discounted costs, maximizes returns to the land and assumes capital is available at the rates listed. The IRR, which is the rate at which discounted revenues equal discounted costs, maximizes returns to capital and assumes additional lands or investments are available. Both have their place in economic evaluation.

There are four management options listed in the tables. Under the "no thinning" option, no activity occurs in the first 10 years. The first harvests occur in year 10 and then every 10 years thereafter until the land is sold in 50 years. Because no volume is removed immediately, there is additional volume, although of lower average quality, harvested in years 10 and 20. At years 30 and 40,the harvests tend to become similar under all options and they are exactly equal in year 50. At that point, a stable selection system is achieved which provides 2,000 board foot and 5 cords of pulpwood per acre every 10 years or roughly .9 cords per acre per year.

Under the "precommercial thinning" option, volume is harvested at year zero and has no viable market. This is seldom the case now, but is included for illustrative purposes. The harvesting done at year zero reduces the volumes harvested at years 10, 20, and 30, but results in higher prices for the volumes harvested due to improved quality. The cost of the precommercial thinning is $53.00 per acre.

In the "commercial thinning" option, the cost of the thinning at year zero is equal to the value received for the material. The "commercial thinning at profit" option results in a payment at year zero which is twice the cost of the thinning. This progression of options is intended to simulate the importance of the development of markets for hardwood thinnings.

Table 1.-- Land Purchased

	No Price Increase		Real Price Increase (1.5%)	
	PNW Discount Rate (2%)	(4%)	PNW Discount Rate (2%)	(4%)
No Thinning				
PNW	$ 7	$-132	$228	$-25
IRR	2.1%		3.7%	
Precommercial Thinning				
PNW	$ 25	$-151	$301	$-16
IRR	2.2%		3.9%	
Commercial Thinning				
PNW	$ 78	$- 98	$354	$ 37
IRR	2.7%		4.4%	
Commercial Thinning at Profit				
PNW	$131	$- 45	$407	$ 90
IRR	3.3%		5.1%	

Table 2.-- Land Owned

	No Price Increase		Real Price Increase (1.5%)	
	PNW Discount Rate (2%)	(4%)	PNW Discount Rate (2%)	(4%)
No Thinning				
PNW	$165	$ 83	$386	$190
IRR	18.4%		23.8%	
Precommercial Thinning				
PNW	$182	$ 64	$458	$199
IRR	6.4%		9.0%	
Commercial Thinning				
PNW	$235	$117	$511	$252
IRR	15.6%		20.0%	
Commercial Thinning at Profit				
PNW	$288	$170	$564	$305
IRR	25.0%		25.0%	

TABULAR RESULTS

Table 1 lists the IRR and PNW achieved with land purchase and sale included; Table 2 with no land transactions included. Discount rates used for PNW are 2% and 4%. Although this may seem low, recall that these are real rates and if a 6% inflation rate is used, compare to 8 and 10% returns from a bank. Also this is the range where PNW moves from positive to negative values and is thus of greater interest.

It is noteworthy that in Table 1 all IRR's are positive, although somewhat low. The rates of return improve consistently from top to bottom reflecting opportunities through intensified management. When real price increases of 1.5% per year (doubles real prices in slightly less than 50 years) are considered, the real rates of return increase by about 2%. PNW's are now positive above 4% (10% inflated rates) when thinnings are accomplished commercially. However, it is also noteworthy that these IRR's are relatively low. Large upfront costs, in this case land purchase, make it difficult to achieve high rates of return from hardwood land management based solely on timber revenues.

In Table 2, where land purchase is not considered part of the investment process, the rates of return and present net worths are much higher. With these higher rates, precommercial thinning now reduces the overall rate of return because it has a fairly low, although positive, rate. If 2 to 4% real rates (8 to 10% inflated rates) are acceptable, then the investment would still be justified. This is reflected in the increased PNW attained for all except the 4% discount rate with no real price increase.

An interesting result occurs in Table 2 in comparing the commercial thinning to the no thinning option. It would seem that a thinning that covers cost should be attractive. However, recall that the early thinning results in lower volume harvests in years 10, 20, and 30, but increased prices due to quality improvement. At these high rates of return (15 to 20%), the improved quality is not enough to offset the decreased volumes which occur early in the management regime. This is not the case at lower interest rates as reflected in the higher PNW which occur at the 2 and 4% discount rate. As would be expected, the commercial thinning at a profit gives high returns and stresses the importance of strong commercial markets for such timber.

CONCLUSIONS

In general, hardwood management does pay. Returns from timber are quite high if the timber alone is not required to cover land purchase costs. If the timber must cover such costs, then the rates of return are equivalent to those paid by banking institutions. Real price increases for timber improve the rates of returns, although not dramatically. As previously stated, some real price increases appear reasonable for this previously surplus resource which is now and should continue to attract new markets.

Precommercial thinning can give returns equal to those available from banking institutions. Careful selection of opportunities can improve the rates somewhat, but even then they are likely to remain in the lower ranges unless quality differences are substantial. This has made the development of commercial markets for hardwood thinnings quite important to the increased production of high quality sawlogs.

Finally, although extremely important to the improved profitability of hardwood management, commercial thinning is not always automatically desirable. It depends on the quality-quantity relationships and the rates of return acceptable to the decision-maker.

This last caveat reminds me of the story about Harry Truman who was always looking for an one-armed economist for his staff. He decided that that was the only way he could get one who wouldn't be able to say "On the other hand." Unfortunately, you have a two-armed economist who says hardwood management pays, but . . .

EXISTING AND FUTURE PRODUCTS FROM HARDWOOD THINNINGS

Edwin Kallio[1/]

Abstract.--Changes in technology will continue to encourage the use of hardwoods for pulp and paper, waferboard, medium density fiberboard, lumber, and energy fuels in the Lake States during the next 10 years. Incentives for export trade will encourage shipments of more hardwood products from the Lake States through the St. Lawrence Seaway.

A recent study by the Office of Technology Assessment (OTA) indicates that the forest products industry is the world's most productive and among the most efficient. The OTA believes that changing technology will continue to make greater and more efficient use of the forest resource than past assessments have assumed (OTA 1983).

Technology has made possible a greater use of timber through utilization of cull trees, limbs, tops, and slash. Technology has made it possible to use species once considered noncommercial. Technology has permitted more efficient end use of many wood products. Presently, more than 95 percent of the wood entering primary processing mills is converted to products, including energy. All this has had a dramatic impact on the use of our hardwood resources. Let's examine some hardwood use trends, product by product, with emphasis on the future potential for hardwood thinnings in the Lake States area.

PULPWOOD

About 5½ million cords of pulpwood were produced for the Lake State's 38 pulpmills and for the region's 10 waferboard and particleboard mills in 1982; about half a million cord equivalents were in the form of whole-tree chips (Blyth and Smith 1984). Use of all hardwoods for pulpwood has increased by about 90 percent during the past 20 years, from 2 million cords in 1962 to 3.8 million cords in 1982.

The use of hardwood pulp has probably increased because of both technological and economic reasons. Technology has permitted increased use of hardwood fiber in bleached pulps for printing and writing grades of paper and in semi-chemical pulp used for corrugating medium. Economically, there may also have been an increase in relative demand for those grades of paper that make use of lower cost hardwood-based pulps (Ince 1984).

The big news today is the construction of a new pulp and paper mill at Quinnesec, Michigan, by Champion International Corporation. The mill will be designed to use hardwood volume in the furnish to utilize the region's abundant

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hardwood timber resource. It is estimated that about 450 thousand cords of dense hardwoods will be used each year. Champion International plans to have the mill in operation by 1986. Other existing pulp mills are also investing in some expanded pulping capacity throughout the Lake States. For instance, the Mead Corporation in Escanaba increased its annual pulpwood requirements by 100 thousand cords in 1982; Consolidated Papers, Inc. will expand pulping capacity at the company's Kraft Division in Wisconsin Rapids in 1984; and Owens-Illinois in Tomahawk, Wisconsin, is studying the feasibility of expanding capacity in the future.

However, the lack of suitable technology has limited the use of dense hardwood fiber in some pulp grades such as unbleached sulphate and in paper grades such as kraft linerboard. One new and exciting development that may solve this problem is called press drying (Setterholm 1979). Press drying, developed by the Forest Products Laboratory in Madison, is a method of drying stiff pulp fibers under a compressive force. It offers a means of getting the highest specific strength and stiffness possible from any pulp furnish and can reduce the energy requirements of paper making. It eliminates the need for excessive pulp refining and results in paper products with superior dimensional stability. It allows for use of hardwood pulp to make paper that has higher compression strength than now attainable, thus giving the hardwood resource a new competitive economic advantage.

A pulpmill equipment firm is now experimenting with a commercial press dry unit and private companies are also doing their own research. Some forest product researchers predict that the first commercial application(s) to produce linerboard and corrugating medium may take place as early as 1986. When fully accepted by the industry, the rate of conversion to hardwoods should be dramatic. If hardwoods such as birch, oak, and maple could be used to supplement by one-third the softwood and aspen currently used in the Lake States, the forest resources could accommodate an enormous expansion in pulping capacity - about a million cords - and provide an industrial base for many more jobs and investment dollars.

WAFERBOARD AND ORIENTED STRAND BOARD

Waferboard and orierted strand board (OSB) are rigid, flat, and dimensionally stable boards produced by compressing particles of wood while simultaneously bonding them with an adhesive. They are usually available in sheets from 4 by 8 to 8 by 28 feet. They are commonly used for sheathing, roofing, and subflooring in houses as a substitute for CDX plywood. A basic difference between waferboard and OSB is that OSB is manufactured with alternate layers of particles oriented at 90 degrees to each other, similar to plywood. It is stronger and stiffer in the oriented direction of the face layers than in the 90 degree or cross direction to the face layers. Waferboard and OSB are manufactured with a waterproof and durable adhesive, generally phenol formaldehyde resin (Borchgrevink 1980).

There are about 18 waferboard plants and 5 OSB plants in the United States, most built since 1980. Six of these plants are located in the Lake States; one additional plant is being built. Other firms are considering the construction of additional waferboard or OSB plants in the United States; one firm intends to erect 10 more before 1987. Undoubtedly, some of these plants will be built in

the Lake States. About 1,250,000 cords of round wood were used in 1983 for OSB, waferboard, and particleboard. Although aspen is the principal species used, waferboard and OSB producers expect to be using more birch and other hardwoods in the future. A new OSB plant in Louisiana will be using medium and high density hardwoods, and this approach is being watched with interest by the rest of the industry.

MEDIUM DENSITY FIBERBOARD (MDF)

Medium density fiberboard (MDF) is one of the most exciting products to come into the market in a long time. It is rapidly being utilized in furniture and woodworking, as well as in applications ranging from interior paneling to doors, jambs, shelves, cabinets, mouldings, and interior stair treads.

MDF is made in much the same manner as particleboard, with a few important exceptions. Before refining, the wood furnish is heated or "cooked"; the semi-plastic wood is rubbed apart into fiber bundles, a resin binder is added, the treated fiber is formed into a mat, and the mat is hot pressed. Further mill treatments include sanding and sawing before shipment. Systems are available to orient fibers as well.

MDF has a combination of qualities that give the user a flat, smooth surface combined with a tight edge that can be painted or finished easily without filling. MDF has excellent impact strength, is free from knots and voids, and has exceptional screw holding capability. It saws cleanly, drills easily, and does not splinter or chip out. Although a relatively new product, its sales have soared as users have found it ideal for their needs.

MDF has grown rapidly in the United States since 1975. In that year, the MDF industry shipped a scant 177 million square feet(3/4-in. basis); by 1983, shipments were up almost 3½ times to 605 million square feet, and the number of customers for MDF had risen dramatically.

Most users agree that the future is bright for MDF and that it will continue its recent growth pattern. The Stanford Research Institute's International Forest Products Planning Service projects consumption of an additional 480 million square feet of MDF nationally by 1990. One MDF plant utilizing 80 thousand cords of paper birch and dense hardwoods will be completed at Newberry, Michigan in 1985. We expect other MDF plants to be built in the Lake States because of the readily available hardwood supplies and closeness to furniture and other MDF markets in the upper Midwest.

FUELWOOD

Currently, between 5 and 6 million cords of fuelwood are being produced for residential use in the Lake States each year. Fuelwood production has been increasing at the rate of about 10 percent each year. Most of the fuelwood is still obtained from nonforest and noncommercial forest land; from nongrowing stock on commercial forest land such as dead trees, cull trees, and sections; from tops and limbs of growing-stock trees; and from saplings. One study by the North Central Forest Experiment Station showed that in 1981, only 15 percent of the fuelwood came from growing stock on commercial forest land (Blyth and others

1984). This proportion is expected to increase in the future. Hardwoods are the preferred species for residential fuels. Thinning of hardwood stands offers an outstanding opportunity to supply this growing demand.

In addition to residential fuels, an increasing volume of wood is being utilized by the pulp and paper industry for energy. Electrical power plants in the Lake States are also interested in converting a part of their boiler capacity to use wood.

Two recent innovations for using wood for fuel are wood pellets and chunkwood. Pellets are made by grinding or hogging wood to small particle size, drying, and extruding the pellets under heat and pressure. Wood pellets are a feasible replacement for fossil fuels normally used in heating homes, small businesses, schools, and other institutions. Many gas- and oil-fired package boilers can be modified for pellet use fairly easily, and several new burning devices on the market are well suited for pellets. Pellet use is well established in domestic, commercial, and institutional northern Minnesota--and these markets are growing.

The NCFES Engineering Research Unit at Houghton, Michigan, designed, constructed, and tested a wood "chunker" that reduces roundwood bolts up to about 9 inches in diameter into chunks. Chunkwood makes better fuelwood than chips for industrial use because it dries faster, burns cleaner, and requires much less energy to produce. Chunks can also be used as raw material for structural flakeboard and composite wood products (Arola and others 1983). The chunker is ideal for processing thinnings and small trees removed in timber stand improvement operations. We can expect to hear more about this new development for a number of different uses in the near future.

SAW LOGS

About 1 billion board feet of lumber are produced by about a 1,000 sawmills each year in the Lake States. About 600 thousand board feet of this volume is sawed from hardwoods other than aspen.

Most of the saw logs produced from hardwood thinnings are relatively low in overall quality. The objective of thinning is, of course, to produce stands with high-quality saw logs and veneer logs. Many of the lower quality saw logs are sawn into lumber for the pallet and container industry. That industry in the United States consumes a volume of sawn wood equivalent to nearly 60 percent of total hardwood lumber production. The pallet and container industry is projected to grow normally at a 4-percent rate from 1985 to 2000 (Anderson and others 1984).

Some of the hardwood lumber is also used for dimension parts for furniture and cabinets. There is much interest in applying a process for cutting, drying, edging, and gluing lumber from low-quality hardwood bolts into high-quality hardwood panels for furniture and cabinets. This "System 6" process, developed by the Northeast Forest Experiment Station's Forestry Sciences Laboratory in Princeton, West Virginia, will be covered in the next session.

INTERNATIONAL TRADE

Hardwood exports from the U.S. now average about half a billion dollars annually. The period of most rapid growth during the last 20 years was from 1973 to 1980, when the value of exports increased by 400 percent. However, exports declined rapidly in 1982. Lumber accounts for more than half of the total value of hardwood exports, followed by logs (22 percent), veneer (19 percent), and plywood (2 percent). About one-fourth of all hardwood exports are shipped out of southern ports. Most of the remainder is shipped out of the North (Wisdom 1984).

The U.S. Department of Commerce, the Seaway ports, the State Departments of Business and Industry, and other agencies are busily promoting exports of both raw materials and manufactured products. The International Trade Administration (ITA) provides assistance to potential exporters in regard to trade promotion, finance, insurance, negotiations, and trade analysis. One impetus for increasing export trade is the recent Export Trading Company (ETC) Act of 1982. This act allows a group of competing firms to combine in export ventures if their conduct does not have substantial anti-competitive effects inside the United States. An ETC can enjoy economies of scale not usually available to small and medium-sized companies operating individually because it exports large volumes of products from many sources at lower per-unit costs.

Very few timber products are currently shipped through the Seaway from the Lake States area. However, there is much interest in developing the export markets for Lake States hardwoods. One example is a continuing study of the possibility of shipping wood fuel pellets from the Port of Duluth, Minnesota, to African nations that suffer from a serious shortage of wood fuel for homes and factories.

CONCLUSION

Based on the best available information on changing technology and increasing demands (and assuming a relatively stable economy), the following is an estimate of the increasing consumption of hardwoods (not including aspen) that will be cut from growing stock on commercial forest land in the Lake States.

	1982	1987	1992
pulpwood (million cords)	1.0	2.1	3.0
fuelwood (million cords)	1.0	1.7	3.5
particleboard/MDF (million cords)	-	.3	.7
saw logs (million board feet)	600	750	900

These are truly exciting times for forestry in the Lake States. Waferboard and OSB have tremendously expanded the aspen market. New technology will allow the use of material from hardwood thinnings and help foresters manage this valuable resource to restore the forest products industry as a major contributor to the economic well being of the Lake States.

At the same time, never in the history of the Lake States have there been more dedicated, enthusiastic, and knowledgeable people working on wood product industrial development than there are today. Research and promotion by the State Departments of Natural Resources, various governor's councils and task forces, regional development groups, the State Departments of Business and Commerce, and the wood-using industries will certainly have a positive impact on the future use of our hardwood resource.

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APPLICATION OF THE SYSTEM 6 PROCESS TO HARDWOOD THINNINGS

Hugh W. Reynolds[1/] and Edwin Kallio[2/]

Abstract.--Additional revenues to support the best silvicultural practices can be gained by selling logs and bolts from commercial cuts to producers of high-valued products. System 6 is a new technology to convert small-diameter, low-grade timber from hardwood thinnings to a new, high-valued product called blanks. This new technology can provide jobs at low investment levels per job while improving the hardwood forest.

Thinning cuts, timber stand improvement (TSI) cuts, precommercial cuts; call them what you will, one fact is common to all: Costs to make the cuts are more than the revenues from the timber removed. These cuts are investments to be realized from the increased stumpage values in future commercial cuts.

Investments in thinning cuts, etc., are difficult to justify when inflation rates exceed the rates of return on such investments. The value of the timber products from these cuts must be increased and the costs incurred in making these cuts must be decreased. In this paper we describe ways that the value of the timber produced can be increased.

There is no way that the timber manager can convert the small-diameter, low-grade timber to produce Factory Grades 1 and 2 sawlogs. The Grades 1 and 2 sawlogs are valuable because a sawmiller can make No. 1 Common and Better hardwood lumber from these sawlogs. In turn, the No. 1 Common and Better lumber is valuable because furniture, dimension, or kitchen cabinet companies can make rough-dimension parts from this lumber.

But, if the rough-dimension parts can be produced from the small-diameter, low-grade timber, then this timber will become more valuable. And if the No. 2 Common and poorer lumber produced when sawing Factory Grades 1, 2, and 3 logs can be used to make rough-dimension parts, then these logs will become more valuable. Using conventional cut-up technology to make rough-dimension parts from low-grade logs and lumber is too costly. Too much waste is produced. Not enough long rough-dimension parts are produced.

What we need is a new solid hardwood product that can be substituted for high-quality hardwood lumber. This new product should be made from (1) small-diameter, low-grade timber; or (2) No. 2 Common and poorer lumber made during the sawing of high-quality logs; or (3) all the lumber, No. 2 Common and Better, called log-run lumber, made from medium-quality sawlogs.

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Research by the USDA Forest Service, together with university cooperation, has solved these needs. The new solid hardwood product is called blanks, which can be made by gang ripping No. 2 Common lumber or log-run lumber. Blanks can also be made from small-diameter, log-grade sawbolts.

Blanks

Furniture and kitchen cabinet parts are made in thousands of sizes. We at the Forest Sciences Laboratory, USDA Forest Service, Princeton, West Virginia, have completed a parts study of 20 furniture and 12 kitchen cabinet companies (Araman 1982). We found that all the required parts could be made from edge-glued panels made in four quality classes, six thickness classes, and in no more than 13 lengths per class (Araman 1983; Araman and others 1982). We call these edge-glued panels "blanks." Recommended standard sizes for furniture and cabinets were established (Araman 1983). A furniture or cabinet company will buy blanks, rip and crosscut the parts from these blanks, and have no more than ten percent end-trim loss (Araman 1983). Making parts from blanks will cost no more, sometimes less, than making parts from high-quality hardwood lumber.

System 6

Blanks can be made from small-diameter, low-grade hardwood timber using System 6 (Reynolds and Gatchell 1979, 1982, 1983). The tree stem is bucked into 6- or 8-foot bolt lengths. The bolts are sawed into two cants. The cants are resawed into boards, and the boards are kiln dried. The boards are then cut up into defect-free pieces in the standard-size blank lengths. The pieces are then edge-glued into standard-size blank widths. Final planing completes the process.

A System 6 research pilot plant has been built at the Forestry Sciences Laboratory in Princeton. We also designed a hypothetical but typical System 6 mill. This $2 million mill has a 21 percent rate of return, after taxes, over a ten year investment period (Hansen and Reynolds 1983). Studies on such a mill using oak bolts from West Virginia and Virginia to make frame blanks for a Tennessee upholstery furniture company and clear blanks for a Kentucky kitchen cabinet company were successful (Reynolds and Araman 1983; Reynolds and others 1983).

We have made System 6 studies using white oak, red oak, cherry, white birch, and yellow-poplar. The low-grade, small-diameter timber came from West Virginia, Virginia, Maryland, Pennsylvania, Massachusetts, and Minnesota. The blanks have been put to commercial test use in furniture and kitchen cabinet companies in North Carolina, Virginia, Pennsylvania, Massachusetts, New York, Minnesota, Wisconsin, and Iowa. System 6 commercial mills are being designed or are under consideration in Minnesota, Wisconsin, New York, West Virginia, and South Carolina.

Gang-Rip Rough Mills

Blanks can be made from the No. 2 Common and No. 3A Common hardwood lumber. This lumber accumulates as No. 1 Common and Better lumber is sawed from high-quality logs. The No. 2 Common and No. 3A Common boards are air dried, kiln dried, hit-and-miss planed, gang ripped into strips, and the strips are crosscut to blank length pieces while removing defects. Pieces with edge defects are edged. Pieces are edge-glued to make blanks.

Gang-rip rough mills are operating presently. The only new requirement for making blanks is that the gang ripsaw must produce glue-joint quality cuts. Both American and foreign machines are available. The gang-rip rough mill lends itself to automation.

Research at the Princeton Lab has shown that a gang-rip rough mill will provide the long pieces necessary for blanks production (Gatchell 1982; Gatchell and others 1983).

Conventional Rough Mills

Crosscut-first rough mills can be used to produce blanks profitably. No. 2 Common and Better hardwood lumber is air dried, kiln dried, crosscut to blank lengths, hit-and-miss planed, and selectively ripped to random-width pieces to remove defects. Pieces with end defects are trimmed to shorter blank lengths. Pieces are edge-glued to make blanks.

Research at the Princeton Lab has shown that conventional rough mills can be practical blanks producers (Araman and Hansen 1983). A completely new conventional rough mill, a $3 million investment, would return 26 percent after taxes on a one-shift basis or 40 percent after taxes on a two-shift basis (Araman and Hansen 1983).

Marketing Blanks

Blanks sell well when the cost of blanks to the furniture and kitchen cabinet maker results in parts that cost as much as or less than parts they produce themselves (Araman 1982). In our research studies, the blanks that we have made have been used by furniture and cabinet makers. Our economic analyses have been made with blanks priced at the low point of the hardwood lumber market (Reynolds 1983). When business is good, high-quality hardwood lumber prices rise sharply. But blanks can be made from low-quality lumber and logs, so blank prices will not rise sharply giving blanks a competitive edge.

A marketing survey in the spring of 1983 was made at eight furniture plants in the New England area. Seven of the eight plants would have bought red oak blanks if they had been available. The eighth and smallest company had its own lumber supply.

The University of Minnesota in cooperation with the North Central Forest Experiment Station, USDA Forest Service, determined markets for white birch blanks. Based on contacts with company executives, the furniture industry in the Upper Midwest is receptive to the concept of wood blanks and to birch blanks in particular (Monson and Bowyer 1982).

The market for blanks to home craftsmen is large. These blanks can carry a much higher price than blanks sold wholesale to furniture and cabinet makers. (Araman and Reynolds 1983). Results of a study in the Upper Midwest and test marketing by distributors in the Minneapolis - St. Paul area indicated a widespread interest in standard size hardwood panels for retail consumption (Michaels and Bowyer 1983).

Blanks have also been shown at the International Woodworking and Furniture Supply Fair-USA (IWF) in 1978, 1980, and 1982. Blanks will be shown again at

the IWF-84, in Atlanta, Georgia, August 25-28, by both research and industry representatives. Prospective blank purchasers and suppliers will be contacted.

SUMMARY

The small-diameter, low-grade hardwood timber removed during thinning cuts does not cover the costs incurred. This timber can be increased in value when it is converted to a high-valued product such as rough-dimension furniture parts. This increase in timber value will not cover all the thinning costs but will reduce the investment necessary to do the work.

Rough-dimension parts can be made from standard-size furniture blanks. Blanks can be made from the small-diameter low-grade timber, using System 6, removed during thinning cuts. When better logs are removed during thinning operations, blanks can be made by gang ripping the lower grades of lumber. Blanks can also be made from mill-run lumber using conventional-type rough mills.

White birch from Minnesota has been made to blanks successfully using System 6. Commercial System 6 mills are being designed for use with white birch. Other species of Lake States' hardwoods can also be used to make blanks using System 6.

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SESSION III - DISCUSSION

Q1. Gerry, do economists ever agree on one particular discount rate for the forest industry as a whole?

A1. (Thiede) No, in fact, the industries themselves do not agree on one discount rate, so it obviously is going to vary considerably. Some can get money cheaper than others; there is no agreement on that. There is always a discussion about what discount rate will be used. Normally what you would do is say. "At what rate can I borrow money?" That may be a key for a number of the industries to determine what their discount rate might be.

Q2. So when you are using 2 percent, you are saying that they can borrow money at 8 percent, and you subtract 6 percent for inflation?

A2. (Thiede) That is correct. In that particular instance, you are saying, "I can borrow money at 8 percent. Or if I have some money, that is my alternative--I can invest it in the bank at 8 percent." That is what you are really comparing. If I am using a 4 percent discount rate for present net worth and inflation is 6, I would make 10 percent. If I can get only 8 percent from the bank, it would be worthwhile for me to invest it in hardwood management in that particular case.

Q3. What were the volume tables used for the hardwoods?

A3. (Thiede) The volume tables are those that I obtained from our silviculturist. They are his best estimates of what we have been able to attain in our 10 years of history. So there are historical records that we have used in our own situation in the State Forest System. They are his best estimates, so they were not any specific volume tables. He agreed that they are fairly conservative. If we erred, I think we probably erred on the low end as to what you can get.

Q4. What is the historical real rate of return for northern hardwoods above and beyond inflation?

A4. (Thiede) I do not know that there is a historical rate; I have not seen one developed anywhere. Our people were saying that they could get 8 to 12 percent in certain instances, but it depends on all the assumptions made. These could include, among other things, whether or not land is purchased, what kind of activity takes place, and what is done in those particular instances on those lands.

Q5. That is not the rate of return I was looking for, but what was the real rate of increase for stumpage?

A5. (Thiede) I do not have a figure on that; he did not give it to me. The real rate of increase that I used--1.5 percent--seems to be very conservative given that you are increasing your market opportunities in these three Lake States, and that we now have a decidedly excess or surplus resource. As markets improve and competition increases, one would expect

that it would be in excess of 1.5 percent--the real rate of increase. I think that is a quite conservative assumption.

(Kallio) I might add a little to that question. In our study of hardwood stumpage rates from 1950 to 1980, we found that it was a flat and sometimes a little downward sloping curve after correcting it for inflation.

PANEL ON FOREST MANAGEMENT PROSPECTIVES: HARDWOOD THINNING OPPORTUNITIES ON NATIONAL FOREST LANDS IN THE LAKE STATES

Myron L. Smith[1]

Abstract.--Five of the National Forests in the Lake States have great opportunities for producing quality hardwoods by thinning pole timber stands now. There are some controls needed on equipment size, skid road layout and time of year for entry.

There are great opportunities for forest management on the Lake States National Forests and hardwoods will play an important role in the overall management program. The States of Michigan, Minnesota and Wisconsin all have recognized the importance of this renewable resource we call timber. My comments apply specifically to the dense hardwoods generally referred to as the northern hardwood timber type as well as oak, paper birch, lowland hardwoods.

In general, the Lake States National Forests will be managing for quality hardwoods on sites capable of growing them. I say generally because as you well know, we manage under the multiple use concept and sometimes over-riding needs from another resource will prevail. Diversity for wildlife habitat is a prime example.

I feel that despite the technical ability to chip, grind, flake and otherwise break wood down and reconstitute it into boards, panels and dimension material, the demand for quality hardwoods will remain. To reach quality product size, there will be a sizable volume of low quality and small size products from thinnings.

There are some concerns and/or limiting factors which need to be addressed if we are to reach full management of all the available acres.

1. Markets for low quality material.--Most National Forests in the Lake States are marketing only half of what could be sold and in many cases, less than half in dense hardwoods.

2. While markets are picking up, the National Forests in the Lake States must compete nationwide for dollars and people to prepare and offer for sale additional timber. Thinning hardwoods is more costly per unit to prepare and administer than many other types which can be clearcut or row thinned such as plantations. This more costly work is coming at a time when the money to prepare and offer sales are shrinking.

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[1]Timber, Wildlife and Fisheries Staff Officer, Nicolet National Forest, USDA, Forest Service, Rhinelander, Wisconsin.

3. Control of harvest operations in hardwood thinnings needs close attention to insure a quality job.

   a. Time of year which operations take place is important as damage potential to residual trees is much greater during the growing season. Also, the soils on which we can expect to grow quality hardwoods are heavier and more susceptible to rutting which can cause root damage and erosion. It is unlikely that all harvesting can take place under frozen conditions so--

   b. Equipment size and type may need to be carefully selected for thinning cuts. Operator skill may have to be demonstrated before one is allowed to operate machinery in the stands.

   c. Skid roads will need to be laid out prior to when the sale is sold. Equipment will be required to stay on them to reduce soil compaction. Some studies indicate that as much as 80 percent of the soil compaction is done in two passes, so by staying on the same skid road will not cause much additional compaction.

   d. Proper residual stand density is necessary to ensure we move toward quality. Too dense a stand reduces growth while over cutting will provide opportunities for loss in quality by sunscald, epicormic branching, forking caused by the maple bud minor and wind firmness.

Thus, while we have a tremendous opportunity to grow quality hardwoods through thinning stands, we must remember that quality control of intermediate cuts is necessary to have quality sawtimber in the future. Without quality control of operations in intermediate cuts, the future never arrives.

Thank you.

LARGE INDUSTRIAL FOREST MANAGEMENT PERSPECTIVE OF HARDWOOD THINNING

Ermine J. Venuto[1]

Abstract.--Land ownership size, long-term objectives, and income alternatives all play a role in how northern hardwood stands should be managed. Foresters have the responsibility to make stand prescriptions that combine silviculture and cash generation for the landowner.

In attempting to present part of the industrial side of forestry, we have earlier heard a number of industrial foresters. As much as we believe in the continued multiple use on our properties throughout the whole forestry center of the Great Lakes, we operate forests as a business. We grow trees to make money; corporate timberland ownership is predicated on this. The Mead Corporation, Owen-Illinois, Champion--none of them would own timberlands if there wasn't a payoff. Sometimes the payoff is in a combination with a facility--a pulp mill, a liner-board mill, whatever alternate uses they might have for it; but obviously, as foresters, we have to show that there is a payoff in terms of our growing trees on these acres.

Mead owns approximately 677,000 acres in the Upper Peninsula. Almost half of it, 380,000 acres, is in the northern hardwood types. We are quite concerned with hardwood management, and we practice a number of different types of forestry in the hardwood types. In Escanaba, Mead anually buys a little over 700,000 cords of pulpwood every year. Some of it is hardwood, some softwood, and some aspen which we use in a specialty process for making pulp. In addition to pulpwood, we purchase and/or harvest from our own timberlands about 20 million board feet of sawlogs a year, primarily dense hardwoods. This gives you some idea of the variety of products that we produce.

Each year we harvest about 6,000 acres on Mead land through clearcutting. Depending on the year and the markets, we also thin anywhere from 12 to 18,000 acres per year on a selective basis. Presently, we plant about 3,000 acres a year to conifers on the 6,000 acres that we clearcut. We let the remaining acreage regenerate back primarily to aspen, spruce-fir, or white birch types. The ongoing selective systems that we use for harvesting are quite conventional. Typically, we thin down to a basal area of 75 to 90 square feet and then revisit the stand, depending on the site index of that particular area and the components of the stand, somewhere in the neighborhood of 8 to 12 years. This is very normal for northern hardwoods, especially with a large component of hard maple type. The reason we return to these stands in the range of 8 to 12 years versus other options is that the trees are growing into new size categories, and the variable sometimes overlooked is that we can afford to return and log these areas because the volume that we can remove after an 8- to 12-year growing period is sufficient to be able to justify a logging operation.

In the beginning, I said the key to the whole thing is being able to economically and cost effectively manage the forest and the timber harvest process,

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[1]Woodlands Manager, Mead Corporation, Escanaba, Michigan.

which is what we sometimes call "silviculture." We need to make that an integral part of the way we put the stand back together and design the long-term needs for it.

However, I don't want to emphasize only company lands because the majority of our purchased material comes through state, federal, and private lands. On those operations, the nice feature about being in the pulpwood business is that we can help in the management of northern hardwood stands. We can manage a small landowner's acreage and remove not only the grade sawlogs that need to be thinned during that particular harvest, but we also can harvest the cull poletimber that would effectively not make anything more valuable in 8, 10, or 40 years from that time. Thus, the complete thinning of a stand is a very important ingredient of it. Only thinning a stand by what has been historically known as hygrading obviously does not help in the long-term development of the stand.

The key in thinning depends on three or four conditions. The first is the ownership objective of the individual. The Mead Corporation, Champion International, large industrial users, Cleveland Cliffs Forest Products, and others all have perhaps a little different type of ownership objective than the small private landowner. Their objectives, their time horizon, which is another factor, are almost infinite. A corporation is formed to go on in perpetuity, so when we manage our lands we manage 677,000 acres; we don't necessarily manage just 1 acre at a time. Therefore it is done on a little different basis compared to a private, small landowner who may have a 40-acre parcel, 10 acres of which are northern hardwoods. He has to put his objectives into a much more localized sense in being able to pinpoint how he would like to take care of the stand.

One of the critical variables is the income source. We can regulate stands of timber on a fairly continuous basis because we have large land holdings. The private landowner, who may have 40 or 80 acres or even a section, won't necessarily have the alternative of regularly being in that stand on a continuing basis. In other words, his income flows are the reason that he frequently harvests that stand. Most private landowners don't like to practice good forestry at all times. Their sons or daughters need to go to college or there is a wedding or some other alternative which has pressed him into cutting the timber. Whenever we or anyone else manage those types of stands, those are the types of situations you are either fighting or you have to agree upon with the landowner--his objectives for income may be the way you have to direct the harvest of that stand. It doesn't mean you have to do a bad job of management, but you certainly have to listen to ownership objectives.

Another critical variable which I continue to emphasize is the size of the ownership. It is difficult for Mead sometimes to leave a 5-acre parcel of northen hardwoods in the middle of a clearcut that we are ultimately going to site convert. The private landowner might take the same 80 acres and manage it on a 5-acre basis rather than manage it on an 80-acre basis.

I want to include a quotation from a publication by Jim Johnson of the Ford Forestry Center which says, "The management goal of the selective harvest system is to maximize volume and value growth while perpetuating a sustained yield forest." One can say the same thing of a clearcut (and I'm not saying it to be facetious), but sustained yield hardwood forests in perpetuity is the underlying theme of this symposium. There are a number of different ways to

evaluate this which is important. Silviculture, including thinning, individual selection, etc., is a tool that the practicing forester has to use and use judiciously. It is just like any other timber harvesting practice. As well as making a decision to thin, there are times when thinning might be an inappropriate practice. You must look at the stands. Some stands may have a negative payback if you begin to thin. I am sure you have all come upon stands of what I would call "clump red maple" with some hard maple in them; you look at the stand and try to decide what to do with these areas. In some cases, it might not be silviculturally appropriate to recommend thinning on those particular areas. It doesn't matter whether it is a private large ownership or the small woodlot, but the initial appraisal the forester makes when he evaluates that stand sets the consequence and the payback for that stand over the future of it. It is important when guidance is given or the timber harvesting process is put into effect that you look at that stand and say not only, "What can we do to it today?" but "What is the potential in 40 years, and what are the options and the pathways that we could use on managing the stand?"

There are a number of other tools that we have, but ultimately everyone in this room realizes that the idea of practicing forestry is somehow profoundly tied to economics--keep the two together. Whenever the prescriptions are made on a stand, you do it in a format that allows that to occur.

HARDWOOD OPPORTUNITIES ON WISCONSIN'S STATE AND COUNTY FOREST

By

James E. Halvorson 1/

Abstract. --Over the next ten years, 3.5 million cord equivalent of hardwoods will be ready for cutting on Wisconsin's public forest. Presently, the majority of available hardwoods fall within the 5-10 inch, pole size class. The marking technique chosen will have an impact on how well the land manager addresses:

- Silvicultural Needs
- Damage Potential
- Logging Chance, and
- Forester Productivity

The goal is to arrive at an adaptable system. One that optimizes the needs of the stand, but allows flexibility in the types of equipment used.

RESOURCE AVAILABILITY

The public ownership in Wisconsin is broken into three catagories: two national forests, six state forests, and twenty-eight county forests which total approximately 3.8 million acres (Fig. 1). The majority of these public forest lands lie in the northern one-half of the state. The hardwood surplus on the state and county forests alone is projected at 230,000 cord equivalent annually. Expanded over the next ten-year period this will be 2.3 million cord equivalent. This is above and beyond the harvest that we have today, and does not include private and federal lands (Table 1).

Table 1. -- County and State Hardwood Surplus.

	*Forcast	*Harvest	*Surplus
County	309,000 cd. equiv.	105,000 cd. equiv.	204,000 cd. equiv.
State	40,000 cd. equiv.	14,000 cd. equiv.	26,000 cd. equiv.

* Annual average (cord equivalent)

Current availability of Wisconsin wood can be found in a recent publication entitled (Timber Forecast: Wisconsin Public Forest 1984/1983) which was published by the Northwest Regional Planning Commission and the Wisconsin Department of Natural Resources. The publication describes in detail each of the individual county forests, national forests, and state forests. Each property has three tables associated with it. An example using Washburn County Forest will be used to show the forecasting information.

Table 1a, describes timber availability. Specifically estimated volumes of timber available for harvest by year and species group over the next ten years are as follows:

1/ Assistant Area Forester, Wisconsin Department of Natural Resources, Spooner, WI.

Figure 1. --

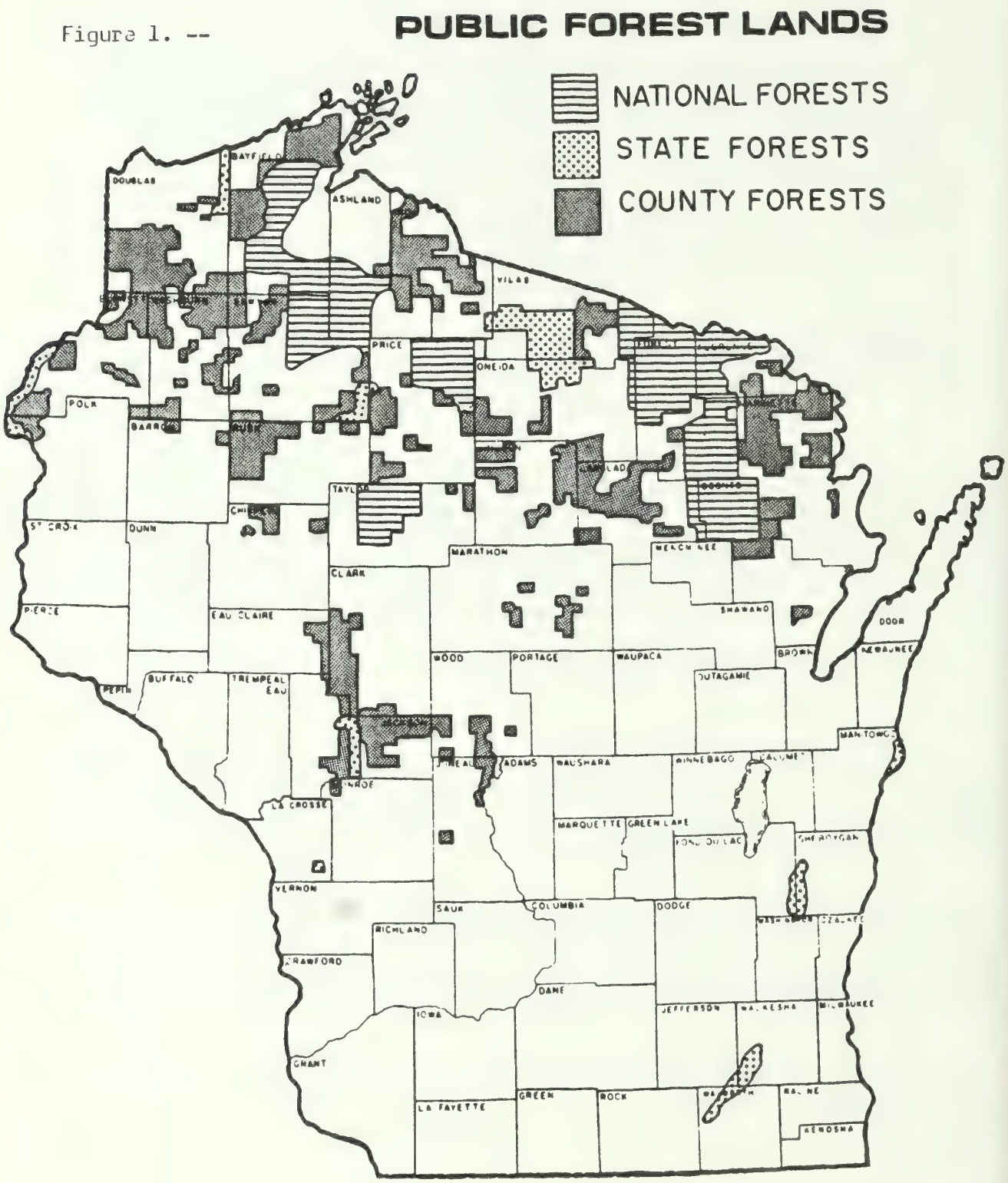

PUBLIC FOREST LANDS
NATIONAL FORESTS
STATE FORESTS
COUNTY FORESTS
DOUGLAS
ASHLAND
VILAS
PRICE
ONEIDA
POLK
DUNN
MARATHON
CLARK
PIERCE
EAU CLAIRE
SHAWANO
DOOR
WOOD
PORTAGE
WAUPACA
BROWN
OUTAGAMIE
BUFFALO
ADAMS
WAUSHARA
WINNEBAGO
MANITOWOC
LA CROSSE
MARQUETTE
GREEN LAKE
VERNON
SAUK
COLUMBIA
DODGE
RICHLAND
CRAWFORD
DANE
JEFFERSON
IOWA
GRANT
GREEN
ROCK
LA FAYETTE
RACINE
KENOSHA

Table 1a. --Estimated Volume of Timber Available For Harvest by Year and Species Groups (1984-1993), (Cord Equivalents).

	Pine	Fir-Spruce	Other Conifer	Hardwoods	White Birch	Aspen	Yearly Total
1984	6,650	6,260	2,680	33,440	4,240	18,120	71,390
1985	6,050	2,280	850	15,790	2,830	13,280	41,080
1986	6,640	1,910	700	14,560	2,870	13,230	39,910
1987	6,020	2,000	610	13,830	2,830	13,230	38,520
1988	6,290	1,690	440	14,010	2,740	13,170	38,340
1989	6,280	1,500	500	12,940	2,670	13,020	36,910
1990	6,170	1,440	440	12,810	2,690	13,030	36,580
1991	6,820	1,360	380	12,640	2,660	13,030	36,890
1992	7,360	1,340	330	12,700	2,670	13,060	37,460
1993	8,080	1,690	480	12,200	2,770	13,240	38,460
TEN YEAR TOTAL	66,360	21,470	7,410	154,920	28,970	136,410	415,540

Table 2a, gives you a timber sale summary over the past 10 years. This is useful in that it gives you the level of activity for each individual species group. It also can be compared to Table 1a to determine surplus above the historical harvest.

Table 2a. -- Timber Sales Summary (1973-1982).

Fiscal Year	Sawlogs (M Bd Ft)	Pine Tamarack (Cords)	Balsam-Hemlock (Cords)	Spruce (Cords)	Aspen Birch (Cords)	Other Species (Cords)	Total All Products (Cord Eqv.)
1973	316.9	7,510	92	-	8,071	481	16,788
1974	155.3	5,288	-	8	10,913	448	16,968
1975	32.9	5,309	209	-	2,537	-	8,121
1976	62.0	4,126	1,050	-	22,815	2,141	30,256
1977	267.7	5,428	-	155	22,218	2,147	30,483
1978	127.7	6,165	42	-	15,373	101	21,936
1979	165.0	8,680	43	-	10,244	1,050	20,347
1980	736.0	7,056	705	214	8,834	2,662	20,943
1981	298.6	6,265	141	75	8,444	3,422	19,036
1982	560.5	3,956	276	90	25,792	5,993	37,398
						TEN YEAR TOTAL..	222,276

Source: WDNR Bureau of Forestry Madison, WI
Northwest Regional Planning, Spooner, WI

Table 3a, shows the commercial forest composition and scheduled harvest by timber type.

Table 3a. --Commercial Forest Composition by Type. 1984-1993 Scheduled Harvest by Timber Type (Acres).

	(Acres)	(%)	Rotation Harvest	Thinning Saw	Thinning Pole
White Pine	444	.3	14	-	197
Red Pine	6,148	4.5	12	-	3,058
Jack Pine ***	13,984	10.3	2,330	-	-
Fir-Spruce	1,821	1.3	721	-	-
Swamp Conifer	1,876	1.4	693	-	-
Black Spruce	2,732	2.0	*	*	*
Cedar	501	.4	*	*	*
Tamarack	1,550	1.1	*	*	*
Hemlock-Hardwoods	37	.	**	**	**
Northern Hdwds	20,510	15.2	-	-	9,906
Oak	11,510	8.4	-	1,900	3,694
Scrub Oak	1,185	.9	688	-	-
Swamp Hardwood	6,983	5.2	2,917	-	-
White Birch	817	.6	175	-	-
Aspen	53,832	39.8	12,300	-	-
Grass, brush, shrubs, etc.	11,464	8.5			
TOTAL COMMERCIAL FOREST	135,278	100.0%			
TOTAL COUNTY FOREST LAND ENTRY	148,216				

* SC, SB, C, T combined in this schedule under SC.
** HH and NH combined in this schedule under NH.
*** Pj regeneration questionable on 5000 acres due to Oak Lake Fire (1980).

THINNING TECHNIQUES FOR POLE SIZE HARDWOODS

Management of pole size hardwood stands have taken a back seat in most areas. Poor markets, high logging costs, and being labor intensive are a few of the reasons loggers and foresters alike have used to avoid these stands. Markets are changing, however, along with the development of new machinery and logging systems. I will be discussing three of these systems: mark selection, strip selection and the strip mark selection. The following are my views on marking and silvicultural considerations, and damage potential from past experience with specialized equipment and labor intensive operations.

First, what kinds of stand are we talking about? The size class is predominately 5-10 inches averaging 9 inches. These are predominately second growth stands, commonly even aged. The basal area is anywhere from 90-200 square ft/acre. The number of stems per acre is running anywhere from 500-700 trees per acre. This would be in the diameter class of 3" and above. The age of the stands run from 45 to 60 years. Most of them originating back in the early 1900's, dating back to the fire and logging era.

Marked Selection.

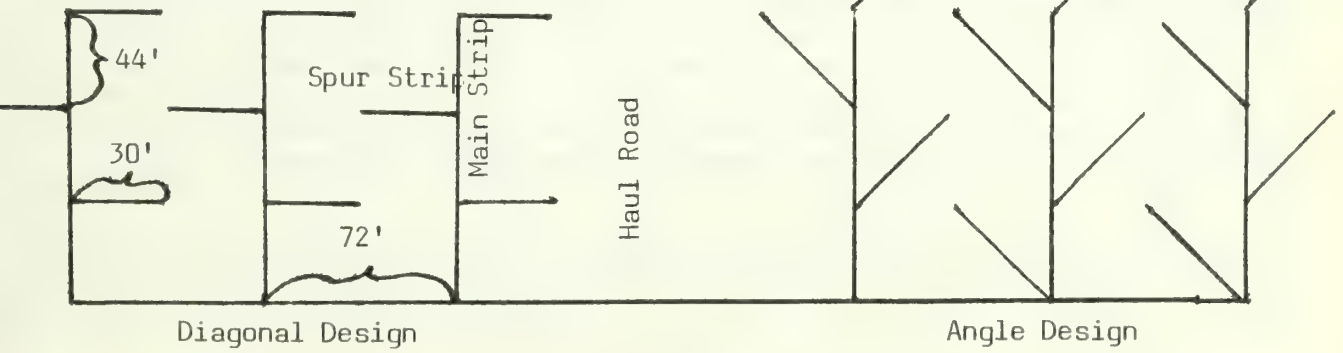
The first system we will discuss is the marked selection method. We all are familiar with how a marked selection works within a saw timber stand. Let us see how it works when it is applied to a pole size situation. The marking considerations are the same. The selection is based on risk, cull, form, species, crown position and size class. A forester in a pole size stand can normally mark one to one and a half acres per hour. This is marking out approximately 6-7 cords per acre.

When you look at the silvicultural aspects of a marked selection in a pole stand, it is one of the best. It is the most adopted or widely used practice when we discuss hardwood marking. However, when one looks at damage, this is where the system has a high potential of failing, particularly when there is poor supervision. It becomes very difficult for a logger to go into a pole size stand with 600-700 stems to the acre without doing damage to the residual crop trees. Damage can be minimized, however, by considering a few contract restrictions. These being: 1) Put a seasonal skidding restriction on the sales. Do not allow skidding operations during the slippery bark period. Particularly during May and June and possibly July. 2) Limiting stringer lengths. A commonly used stringer length for saw timber stands is 16 feet. Practicality of this restriction on pole size stands is doubtful. Many of the trees here being harvested are only 2-3 sticks. 3) Limit skidder size particularly width. A specific width should be determined by the local land manager by reviewing the available machinery in the area. 4) The fourth restriction and probably the most important, is close sales administration followed by penalities. The operator must have a clear understanding of what is expected of him before he begins a sale. I guarantee if you put all four of these restrictions on a sale, you won't have any damage, but you may not have any loggers cutting your sales, either!

Strip Cut.

The next system, the strip selection or strip cut is also a method that can be used in pole sized hardwoods. The design we have used is similar to a wish bone pattern. (Fig. 2).

Figure 2.-- Strip Cut.



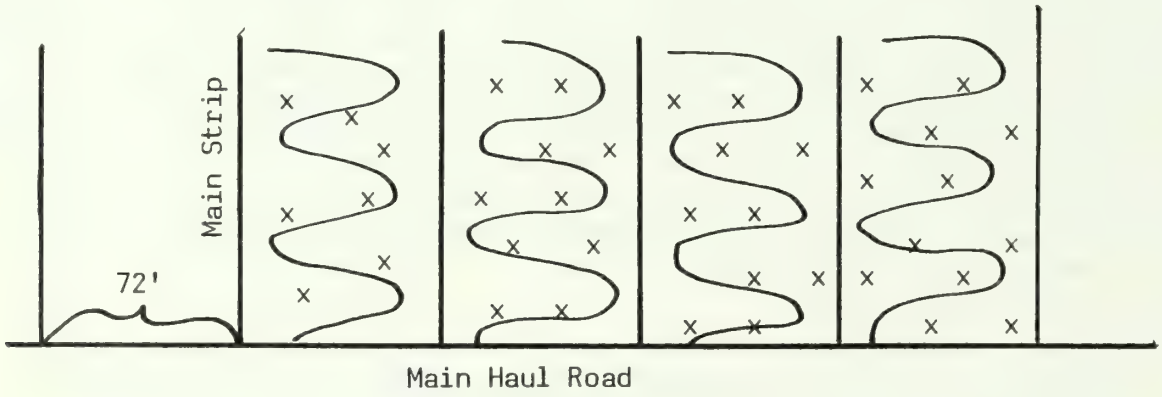
It was felt this system would best facilitate our loggers present degree of mechanization. This is manually felling followed by a cable skidding. Marking considerations are based on the main strips being cut to a 10-foot width and spaced approximately 72 feet apart. Spur strips are then marked and set at a diagonal or angle to the main strip. The spur strips are 44 feet apart and are 30 feet long. Cutting width of the spur strip is approximately 2-3 feet wide. This type of marking requires minimal skills as trees are being marked strickly by a compass line. Spacing and width of strips are dependant on final stocking levels desired and vary with individual stands marked.

Silvicultural aspects on this type of cutting scheme are the poorest. Trees marked are based strictly on your compass heading. There is no consideration to any of the other factors I mentioned earlier in the marked selection to improve quality. However, this type of cut may have possibilities if you are working within a low-site hardwood stand where quality is not important, but are more concerned with fiber production. Damage potential was the least in this design. It was limited mainly to the pivot trees associated with the spur and main strips. Foresters marking productivity in this type of marking system is approximately 2½ acres per hour.

Strip, Marked Selection

The final cutting scheme is a strip, marked selection. (Fig. 3).

Figure 3.-- Strip, Marked Selection.



It is similar to the strip selection with the operation of the machinery being limited to your main strip. Strips are put in 72 feet apart, but may vary with the type of equipment used. A distance of 72 feet apart was chosen in our cuts anticipating manual felling followed by cable skidding from the main strips. After your main strips are layed out the forester selectively marks between these strips. The foresters marking productivity in this type of marking scheme is the fastest averaging 3.7 acres per hour. This is a good scheme to use in conjunction with the private land owner. The owner can mark out the strips with a compass while the forester selectively marks the stand within the interior.

Silviculturally this system is a good compromise. Access is provided into the stand, and you also selectively mark and improve the quality within the strips.

Damage associated with this system was variable, dependent on the type of equipment used and the season it was logged. Here I would like to stress again season. Even a good operator with a small tractor and jammer can do considerable damage during your loose bark period.

I had the opportunity to see the Timco Feller Buncher followed with the grapple skidder working in this particular cutting scheme. Identical stands were cut but during different seasons, spring versus fall. The spring cut site had moderate to heavy logging damage while the fall cut showed very little damage and was confined mainly to your major pivot trees. Because of this and other spring cuts we have seen, we normally put on as a minimum a no skidding restriction during May, June and July.

One additional point associated with both strip methods of cutting is the road cost. It has not yet been discussed, but is a substantial cost when considering a highly mechanized logging system. When laying out the main haul road systems for your strip method cuts we attempt to stay within a 1/8 to 1/3 mile maximum skid.

CONCLUSIONS

There are three points I want to stress with you before leaving. 1) Be adaptable. Listen to the logger and the researchers. Take the best of both and fuse their ideas together. 2) Minimize damage. Stem damage to our pole stands today will be with us for the next 50 to 100 years. 3) Develop a cutting system on your forest that can be used with a variety of different pieces of equipment. Very seldom does the forester know before hand the exact piece of machinery or operation that will be used in a particular stand.

The strip cut with the mark selection between has the potential of addressing these points. One can go in with a fully mechanized system (Feller Buncher with Grapple Skidding) or with a small ma and pa operation. Both operations will come out fairly good.

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SAWMILL INDUSTRY VIEWPOINT

Richard Connor, Jr.[1]

Abstract.--A number of concerns are listed in regard to hardwood thinning. They include a concern for the public agencies to emphasize hardwood thinnings in their timber sales at the expense of sawtimber stands, lack of markets for basswood, the abandonment of railroad transportation, over-thinning, conventional skidding versus the strip method, and the need to acquaint our elected officials with the fact that the hardwood forest can support increased harvests.

Since 1969, Pine River Lumber Company has purchased approximately 10,000 acres of northern hardwood timberland. These lands are basically pole stands. Being close enough to the Wisconsin pulpwood market, we have been able to operate them using the conventional small forwarder and pole skidder operations. We believe these lands are in good shape, and we have marketed most all the products that we would want to develop from them.

Goodman Forest Industries, which we took over from Louisiana-Pacific on October 1, 1983, is a veneer mill and a sawmill which operates a cutting license on 70,000 acres of lands owned by Universal Oil Products, Inc. in Florence and Marinette Counties. In the past, these lands have been logged basically for the 6.2 million feet of sustained yield sawlog and veneer log production that is available off that acreage.

Little attention has been given to the tremendous pulpwood production. We are starting this year to operate the pulpwood acreage, and with continued improvement in pulpwood consumption, we will be able to develop this resource and properly manage this heretofore idle pulpwood resource. At present, on these lands, we are using conventional forwarder-type skidding equipment. Universal Oil Products has allowed us to use John Deere and Gafner Iron Mule forwarders in place of the old D-2 Caterpillars, which they favored for years.

I personally own approximately 3,000 acres of hardwood timber that are being selectively cut using forwarder and pole skidder-type operations, so you can see that I do have a commitment to the management of northern hardwood forests.

I have some concerns in the thinning of our hardwood forests. My first concern is the anxiety of our public agencies to thin hardwood pole stands now that hardwood markets seem to be coming available. I caution them not to forget the sawmills that are dependent on log production off our Federal, State,

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[1]President, Pine River Lumber Company, Long Lake, Wisconsin.

and County forest lands. These mills need 10-inch and larger sawtimber and cannot operate on box bolt-type thinnings. Many of these mills do not have timberlands of their own to fall back on. Mills like this include Steiger Lumber Company at Bessemer, Michigan; Wenos Lumber Company at Iron River, Michigan; and my own company, Pine River Lumber Company at Long Lake, Wisconsin.

Point number two--we need new markets for basswood. Many of the pole stands in my area contain as much as 50 percent of their volume in basswood. The debarking problem prevents it from being used for waferboard production where it would make an ideal raw material. It seems to me that we can fix the satellite in space, but we cannot debark basswood. There is room for research in that area.

Point three--transportation. We cannot continue to let our railroads abandon right-of-way at will and place more burden on truck transport and our already neglected state highway systems in Wisconsin and in the Northern Peninsula of Michigan. It is my belief that Michigan will be forced to adopt the Federal standard of 80,000 pounds. Just think for a minute, if you will, the added traffic that will put on our highway system.

Point four--I do not know how many of you are privileged to know Bob Colby. Bob was a forester with Connor Forest Industries, and I think he worked for the company about 35 or 40 years. Bob often mentioned that some of the best pole stands he had ever seen had never seen a power saw. They have been thinned by Mother Nature and have achieved the necessary height by reaching for sunlight. We, in the sawmill business, know that height is important to the production of quality sawtimber, and I caution that thinning too early can give us diameter growth at the expense of height and epicormic branching.

Point five--I tend to favor conventional skidding in hardwood timber over the strip method. Especially in my area, the high percentage of basswood creates a high volume of unsalable product.

Point six--I understand the Forest Service, in fiscal 1985, proposed funding that will support a cut of 11.2 billion feet. In talking with Jim Berlin, the supervisor of the Nicolet National Forst, he felt it is time to acquaint our elected officials with the fact that the hardwood forest in the Lake States has the potential to support increased harvest opportunities.

Point seven--I believe in the intensive multiple use management of our hardwood forests. I do not think we should thin these forests to the point of conversion. I have seen too many good hardwood forests slashed and converted to aspen and red pine, and I am certainly not in favor of that on our public forests nor on our forest croplands in Wisconsin and Michigan.

RESEARCH NEEDS FOR HARDWOODS IN THE LAKE STATES

David F. Karnosky [1]

Abstract.-- Significant progress has been made in the management and utilization of hardwoods in the Lake States over the past thirty years. However, there is much room to improve on the current growth and use of hardwoods in the Great Lakes Region. For example, the substantial hardwood resource in the Upper Penninsula of Michigan is greatly underutilized. Additional research accompanied by transfer of information to the forest products industry is needed in order to more effectively use our hardwood resource. Seven research priorities are presented in this paper.

I am a forest geneticist -- not a hardwood manager. However, in examining research priorties at Michigan Technological University, I have had the opportunity to discuss research needs for both conifers and hardwoods with representatives from industry, university, and government in the Lake States. Thus, it seems appropriate that I summarize some of what I perceive as the most important research needs for hardwoods in the Lake States. To put this paper in perspective, let me first say that this is an extremely complex topic, because research needs vary from agency to agency and from company to company within a given industry. It is a good one for a geneticist to discuss as we are accustomed to dealing with variation. I will present seven research areas, and I will outline some open questions for each area.

First, there is much we still need to know about site evaluation. What species and what stocking levels are optimum for a given site? Often times in the Lake States, we are faced with mixed hardwood sites or hardwood/conifer combinations which have been cut over once or twice. Thus, it is generally difficult to determine what are the best uses for those sites by looking only at the existing trees. Coffman et al. (1983) have developed a site evaluation system that is proving very useful in determining the best uses of a given site but this system needs additional testing, especially outside of the Upper Peninsula of Michigan.

In contrast to the opinions of some of the other speakers at this meeting, I think we still do not know all we need to about all-age hardwood management. For example, what are the best ways to move a stand to an all-age system? What are the most cost effective ways of doing this, and what are the best ways to maximize returns? How fast should we bring existing unmanaged stands into the all-age management system? In my opinion, these are still open questions. We have certainly gained a lot of experience over the last 30 to 40 years through the extensive efforts by Arbogast (1957), Crow et al.(1981), Erdmann (1983), Tubbs, (1977) and others, but there is

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still considerable refining to be done.

The area of growth and yield modeling still is an exciting area for research, especially to include in-growth, mortality, and changes in log quality in these models (Buchman and Shifley, 1983, Reed et al. 1985). Growth models are also needed for mixed species forest stands so that interspecific as well as intraspecific competition is accounted for (Lynch and Moses, 1983).

Michael Thompson of the Forestry Sciences Laboratory, North Central Forest Experiment Station at Houghton, Michigan gave a very intriguing talk on harvesting equipment and techniques at a recent Xi Sigma Pi Forestry Symposium at Michigan Technological University. It was exciting to see some of the new machines that are being developed used to harvest, delimb, and process trees. It was pointed out, however, that we still do not have a machine to delimb hardwoods. Such a machine could greatly improve logging efficiency with small hardwood trees and so engineering research is warranted here. Additional research and demonstration of the chunkwood production system described by Arola et al. (1983) is neccesary to document the great potential of this system for processing fuel wood from low quality hardwoods or from hardwood thinnings or for producing materials for composite wood products.

As Johann Bruhn, Carl Trettin, and others at this symposium have pointed out, there is a need for additional study of ways to minimize damage to the residual stand and also to the site with harvesting, skidding, bunching, and loading equipment. Few thorough studies have been done to detail logging-related damage to either the remaining trees or to the site. And even less information is available on colonization of selectively-logged stands by pathogenic fungi.

Perhaps the most important research area is in developing ways to increase utilization of low-quality hardwoods and hardwood residues. Development of new composite wood products, finding ways to combine wood with plastics, and exploring ways to decrease the weights of composite wood products are important research areas. One of the areas that is currently being studied at Michigan Technological University's Institute of Wood Research is a way to decrease needs for synthetic glues in composite wood products. Researchers are examining various microorganisms that can break down bonds in wood and open up natural bonding sites. Methods for marketing our Lake States hardwood products in and beyond our region are also needed.

Hardwood management has been shown to yield some favorable rates of return on investment as has been shown by Jim Johnson at this meeting. However, additional economic studies of this type must be done on more sites in the Great Lakes region. McLintock (1979) also pointed out the need for economic studies for hardwood management by small private land owners.

SUMMARY AND CONCLUSIONS

I have described seven research priorities for harwoods in the Lake States. Five of the seven (site evaluation, growth and yield information, economics, equipment for converting and preparing woods residue for use as fuel, and increasing utilization of low quality hardwoods) were listed among the highest research priorities for eastern hardwoods by the Hardwood Research Council (McLintock, 1979).

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CONVERTING TIMBER STAND IMPROVEMENT AREAS TO COMMERCIAL THINNING IN THE NORTHEASTERN AREA

Lloyd R. Casey[1]

Abstract.--Since 1979, fewer acres of timber stand improvement have been completed. Better markets for fuelwood and chips have enabled the thinning to be completed commercially. Problems associated with completing the needed thinning include: local restrictive cutting ordinances; limited markets in localized areas; small size tract per average woodland owner; and lack of available professional forestry advice. Solutions to these problems come from all foresters, both public and private, working together as a team.

The 20 Northeastern States contain approximately 157 million acres of commercial timberland. Of this figure, 35 percent or 55 million acres are in the pole-size class. Although some of these stands have been thinned and there are older stands that could be thinned, these 55 million acres provide a good representation of the potential acres needing thinning (table 1) U.S. Department of Agriculture, Forest Service 1978).

Table 1.--Pole-size stands in the eastern U.S.

State	Thousand acres	Million cubic feet	Cubic feet/acre
Connecticut	600.1	1131.8	1,886.019
Delaware	83.3	214.4	2,573.830
Illinois	944.7	1,700.5	1,800.042
Indiana	818.1	1,472.6	1,800.024
Iowa	356.6	641.9	1,800.056
Massachusetts	947.2	1729.2	1,825.591
Maryland	665.5	1,171.1	1,759.730
Maine	5,339.6	12,193.8	2,283.654
Michigan	8,271.5	14,888.7	1,800.000
Minnesota	8,032.6	14,458.7	1,800.002
Missouri	4,927.5	8,869.5	1,800.000
New Hampshire	1,555.6	3,338.3	2,145.989
New Jersey	388.1	687.7	1,771.966
New York	4,375.3	6,531.9	1,492.903
Ohio	1,537.9	2,267.7	1,474.543
Pennsylvania	5,008.1	9,865.2	1,969.849
Rhode Island	133.0	199.2	1,497.744
Vermont	954.5	744.7	780.199
West Virginia	3,959.6	5,466.3	1,380.518
Wisconsin	6,584.2	11,851.6	1,800.006
	55,483.0	99,424.8	35,442.670

[1]Rural Forestry Assistance Specialist, Northeastern Area, State and Private Forestry, USDA Forest Service, Broomall, Pennsylvania.

Conservatively speaking, about one-third of the stocking should be removed in order to bring these stands into optimum growing conditions. This means that there are presently 33,141 billion cubic feet or 414 million cords available for harvesting. This does not count those stands that should be clearcut for various management purposes.

OPPORTUNITIES

Until recently, all markets for roundwood required clearcutting if the timber was purchased. However, several changes have occurred in the marketplace.

New equipment has been developed that has made thinning existing stands more profitable. Increased markets for soft hardwood for the manufacture of formulated board products have made thinning of hardwood stands more profitable. The increases in the cost of fuel oil have brought on an unprecedented demand for fuelwood.

Only six states in the area do not have sufficient demand for fuelwood to have a ready market for stumpage; i.e., Illinois, Indiana, Iowa, Missouri, Ohio, and West Virginia. We have witnessed the rise in the value of fuelwood stumpage from nothing to $20.00 per cord in a matter of a few years. In 1979, while employed with the Navy Department, I offered a fuelwood sale of over 100 cords of red maple. The offers varied from, "How much will you pay me to clear the area?" to, "I'll take it off your hands at no charge." Today this area in Massachusetts is buying fuelwood stumpage at $10.00 per cord. New Jersey has seen stumpage prices rise to $30.00 per cord in some areas. The States of New Jersey and Connecticut have had to institute a lottery system in order to allow residents to purchase fuelwood from the States' forest land.

In the last five years, timber stand improvement (T.S.I.) operations supervised by State Forestry organizations on private land in the 20 Northeastern States have dropped from 100,000 acres in 1979 to 67,000 acres in 1983 as shown in the following tabulation.

Year	Acres	Percent of 1979
1979	99,854	
1980	101,225	102
1981	90,410	91
1982	78,507	79
1983	67,290	68

Most of this has come about because of the increased use of fuelwood.

As I see it, all this demand has been generated because of the high cost of energy. People have turned to wood as the main source of heat. Some areas in New England report that over 40 percent of the residents use wood as a primary source of heat.

Even though the trucking industry has been de-regulated, transporting lumber and other forest products from the West Coast has become a very expensive business. Corporations are seeking manufacturing locations close to the resource and near the market. Over 58 percent of the population of the United States lives within the Northeastern Area.

All this activity has concerned many conservation organizations. One New York government official has warned that the State of New York could be stripped of its wood resource, while others are concerned that high quality timber will be burned for fuel rather than being made into high quality furniture and other products.

During a recent public hearing, a Sierra Club official requested an expansion of the State's service forestry programs because so many people were being persuaded to harvest their timber at low stumpage prices and then clear-cutting these young stands.

The demand for forest products has been high enough to keep stumpage prices stabilized throughout the recent recession, although over the 20-state area they did not keep up with inflation.

PROBLEMS

With all these good markets, high prices, and adequate supply, why isn't all the thinning being done? Loggers now have to contend with many new regulations. Local cutting ordinances have effectively stopped many logging operations. The State Forestry organizations of Massachusetts, Connecticut, and New Jersey have written model ordinances in order to be sure that owners can manage their forests for timber products.

Localized market areas and small acreages are also problems in certain localities. The average size ownership in the Northeastern Area varies from 10 acres in Connecticut to over 90 acres in Maine. Seventy-two percent of the owners own less than 10 acres (Birch et al. 1982). Many owners have acreages too small to manage economically, unless they join with neighbors in order to have holdings of sufficient size. Some of these lands are managed only for the owner's fuelwood.

Another problem that prevents the proper thinning of forest stands is the lack of professional assistance. Of all the timber that is harvested within the Northeastern Area, less than 11 percent of the owners have the assistance of a forester of any kind. The State Forestry organizations service about 3 percent of these harvesters.

At the present time, there are approximately 300 State Service Foresters (down from 495 in 1980) available for assistance to landowners, and there are over 600 private consultant foresters assisting in this effort. This means that there are less than 1,000 foresters for 157 million acres of forest or one forester for every 157,000 acres. This does not take into consideration the number of industrial foresters that are available because the figure is not available. If we guessed that there were 500 industry foresters, the forester to forestland ratio would be 1:112,142, which is unacceptable for proper forest management.

The last major reason that landowners do not thin their forests is that they have a bias against cutting. Landowners' studies conducted by the Northeastern Forest Experiment Station show that less than 50 percent of the owners surveyed would be harvesting in the next 10 years. When queried as to the main reason for owning timberland, aesthetics and wildlife were stated far more often than timber production.

CONCLUSIONS

In summary, the markets for hardwood thinnings are available in many areas. There are sufficient acreages of pole-size stands in need of thinning, and prices have risen for fuelwood in many areas to encourage landowner participation in more intensive forest management. Logging equipment has become more sophisticated, and they can operate in the woods more efficiently and economically than in the past. However, there is a need to determine the proper mix of equipment for an efficient thinning operation.

However, there are many stumbling blocks in the way of getting the job done. Local cutting ordinances are in need of monitoring and changing in order to meet the needs of the landowners, loggers, and the township taxpayers.

There are still areas that need markets. These states are also the same states that have been blamed for acid rain production. If the coal burning utilities would burn a coal-wood mixture, one benefit is a major reduction in the sulfide emissions, and in turn, a market for the thinning material would be available to the landowners.

The formation of forest management districts or landowner cooperatives for the management of small parcels would bring more timberland under proper forest management in economical units.

The last two problems may be the most difficult to overcome. But I believe that the cooperation of all foresters, including industrial, government, and private consultants, can solve the problems. More foresters are needed in the field. I propose that the Federal government provide assistance to new consultants coming into practice. State foresters provide those services that cannot be financed from the proceeds, such as the development of management plans and education of landowners and the general public as well. The consultants in turn would follow the management plan as a referral. In other words, there would be teams of foresters--the public foresters providing umbrella services with specific on-the-ground work being done by the consultant. With the increased activity within a community, I am sure that more timber management will take place. I predict that, within a few years, commercial thinning will increase to the point of possibly eliminating TSI operations as a major forest management practice. Thinning will no longer cost; it will pay and, hopefully, be done on a large scale.

TIMBER SUPPLY AND HARDWOOD THINNING OPPORTUNITIES ON MICHIGAN'S NONINDUSTRIAL PRIVATE FORESTS

Eugene M. Carpenter[1/]

Abstract.--Nonindustrial private forest landowners control 58 percent of the hardwood forest resource in Michigan and provide 70 percent of the annual removals of hardwood growing stock. Though timber production is not an important objective for NIPFL's, most of their timber will be available in the long run. Whole-tree thinning may encourage these owners to harvest. Thirty-one percent of the owners who said they never planned to harvest indicated they would consider a whole-tree thinning. Owners' attitudes towards timber harvest often change over time.

In the brief time I have, I'd like to talk about nonindustrial private forest landowners (NIPFL) as timber suppliers; their control of the hardwood forest resource in Michigan; how timber harvesting intentions and actions change; and how this is influenced by tenure, size class of ownership, and residency.

First, I'd like to tell you where I think NIPFLs stand as timber suppliers, and how thinning--especially a whole-tree improvement cut--could increase short run timber supplies from these ownerships.

In a recent statewide study of nonindustrial private forest landowners in Michigan, we asked owners if they intended to harvest timber in the next 5 years, 5 to 10 years, sometime in the future, or never (table 1).

Table 1.--Estimated number of private owners and acres of commercial forest land owned, according to time of future harvest, Michigan, 1981[a/]

Time of Future Harvest	Private Owners		Acres Owned	
	Number	Percent	Number	Percent
In next 10 years	84,350	22	3,092,350	35
Sometime in future	101,550	26	3,224,550	37
Never	153,200	40	1,832,950	21
No answer	44,600	12	648,550	7
Total	384,700	100	8,798,400	100

[a/] Includes all private owners of 1 to 9,999 acres of commercial forest land. Excludes forest industry owners.

[1/] Market Analyst, North Central Forest Experiment Station, USDA Forest Service, Duluth, MN.

Statewide, we estimated 48 percent of the owners plan to harvest sometime, 40 percent never intend to harvest, and 12 percent did not answer the question. Forest land owned by these groups were 72 percent, 21 percent, and 7 percent, respectively, of the commercial forest acreage owned by small nonindustrial private forest landowners in Michigan.

Later, we asked owners if they would consider a whole tree thinning to improve the growth and quality of the residual stand and possibly improve wildlife habitat and woodlot appearance. We indicated this might be possible if markets were available for small and low quality material such as fuelwood. Thirty-nine percent of the owners holding 63 percent of the forest land said they would be interested. Not quite as many were interested in thinning as in harvesting.

But, let's look at the 21 percent of the owners who said they never intend to harvest to find out how they felt about an improvement cut. They own over 1.8 million acres of commercial forest land. To begin with, 47 percent of these owners (holding 42 percent of the 1.8 million acres) said they would not consider an improvement cut (table 2). These owners represent 19 percent of all owners and hold 9 percent of all forest land in Michigan.

Table 2.--Estimated number of private owners who never intend to harvest timber and the acres of commercial forest land they own by their interest in a whole-tree thinning, Michigan, 1981[a/]

Interest in Whole Tree Thinning	Private Owners		Acres Owned	
	Number	Percent	Number	Percent
No	71,950	47	782,850	42
Yes	47,150	31	817,500	45
No answer	34,100	22	232,550	13
Total	153,200	100	1,832,900	100

a/ Includes all private owners of 1 to 9,999 acres of commercial forest land. Excludes forest industry owners.

However, 31 percent of these owners holding over 817,500 acres--these are owners who said they have no intention to harvest timber--said they would consider a whole tree improvement thinning. I maintain that this indicates slash or clearcutting are deterrents to harvest in the minds of some NIPF owners. And, that, if needed, more fiber can be available from the NIPF source by using whole-tree thinning.

Tying this to the theme of the symposium--hardwood thinning--we find that NIPFL's in Michigan:

Own 53 percent of the commercial forest acreage
Own 58 percent of the hardwood forest type
Own 55 percent of the hardwood poletimber acreage

Own 58 percent of the hardwood growing stock volume
Own 60 percent of the hardwood sawtimber volume

Generate 60 percent of the hardwood growing stock growth
Generate 60 percent of the hardwood sawtimber growth

Provide 70 percent of the removals of hardwood growing stock
Provide 76 percent of the removals of hardwood sawtimber

Cut only 54 percent of the total growth of hardwood growing stock on their lands annually
Cut 55 percent of total growth of hardwood sawtimber on NIPF lands annually

Thus, NIPFL's control a major share of the hardwood forest resource in Michigan. And these statistics reinforce the position of NIPFL's as important timber suppliers. Relative to their share of owning the hardwood resource they are providing their share or more of the timber cut. Yet, they are removing only slightly over half of their annual growth.

Bob Stone, in 1967, first realized the seeming inconsistency between case studies showing that a significant proportion of nonindustrial forest landowners would reserve their timber from harvest and forest survey statistics showing that NIPFL's provide a proportion of timber harvest consistent with their share of timber volume and growth--and equal in proportion to other owner classes (Stone 1970).

Now, for those who are concerned about nonresident owners as timber suppliers, our study showed that 53 percent of these absentee owners holding 28 percent of the nonresident held forest land (or about 8 percent of all forest land) said they had no intention to harvest timber (table 3). This compares to 38 percent of resident owners holding 18 percent of the resident held land (about 11 percent of all forest land). Fifty-two percent of these nonresidents with no intention to harvest (holding 58 percent of the land) said they would think about an improvement cut. Nonresidents appeared to be somewhat more receptive to whole tree thinning than residents.

Similarly, owners of half the land in the 1- to 49-acre size class, that have no harvest plans, showed an interest, especially those who own larger tracts in the class. Webster and Stoltenberg (1959) were among the first to report that size class of ownership had a direct influence in predicting response to forestry programs. We demonstrate somewhat the same thing here. The average size of ownership is 36 acres for those with positive harvest plans, 32 acres for those with indefinite harvest plans and 12 acres for those who never plan to harvest. The average ownership expressing an interest in an improvement cut is 37 acres. The average size holding for owners who never plan to harvest but would consider a whole-tree thinning is 18 acres and only 11 acres for those who would not.

Table 3.--Estimated acres of commercial forest land owned by residents and non-residents who never plan to harvest timber, by their interest in a whole-tree thinning, Michigan, 1981[a/]

Harvest Decision	Acres Owned by Residents		Acres Owned by Non-residents	
	Number	Percent	Number	Percent
Never plan to harvest	947,100	18	693,650	28
Interest in whole tree thinning				
No	468,100	49	234,900	34
Yes	370,700	39	401,300	58
No answer	108,300	12	57,450	8
Total	947,100	100	693,650	100

a/ "Residents" live within 25 miles and "non-residents" live 50 miles or more from their nearest forest tract. Owners with nearest tracts from 25 to 49 miles own 69,250 acres and are omitted here.

Consequently, if one feels more fiber may be needed, whole-tree improvement thinning may be the key that unlocks the door to nonresident and smaller sized ownerships. Because immediate returns to the landowner may not cover costs of thinning, consideration should be given to promoting improved wildlife habitat, improved appearance of the woodlot, improved quality, value, and growth of the residual stand.

Now, we've been talking about the short run. And there are those who are fed up to here with statistics relating intentions, attitudes, and characteristics of NIPF owners. We characterize these owners as being completely disinterested in timber production as an objective for owning forest land. And that's what they tell us for the most part. But, we should recognize that they have been holding their own as timber suppliers.

And one possible reason is highlighted in a recent study of NIPF landowners in the Upper Peninsula that included an analysis of change during three time periods (Quinney 1960, Stone 1970, Carpenter, in preparation). We found that the proportion of owners holding a particular intention does not change much. But for a particular ownership (piece of forest land) intentions held by the current owner often have changed--mostly because different owners have different intentions and partly because the same owners change their minds.

In comparing ownership information beginning with a base forest acreage of about 20,300 acres in 1960, we found that 46 percent of the owners of forest land from the original 1960 base were different in 1967. Fifty-five percent of the owners of the 1967 base were different in 1979. And 72 percent of the owners in 1979 were different than those in 1960. (To be an "owner" in 1967 and 1979 each had to own at least a piece of the original 1969 forest acreage).

However, some stability is apparent. From 1960 to 1979, 28 percent of the original ownerships were still held by one original owner, though the forest acreage reported may have changed. About half the owners had within a few acres of the same amount as in 1960, one-quarter had more, and one-quarter had less. (These original ownerships amount to 21 percent of all 1979 ownerships).

Furthermore, from 1960 to 1979, an additional 38 percent of the original owners still own at least a part of the original 1960 forest land. (These original owners amount to 28 percent of all the 1979 owners).

What we have seen, however, is a tremendous change in owners and it is not surprising that this impacts on attitudes, intentions, and actions.

In documenting changing attitudes toward timber harvest we found that thirty-five percent of the responding resident owners had a change in attitude from 1967 to 1979.

--43 percent changed to positive and half of these were different resident owners of property formerly held by a resident

--57 percent of the residents changed to a negative attitude and 63 percent were different resident owners.

Forty-five percent of the responding nonresident owners had a change in attitude from 1967 to 1979.

--60 percent of the shift was to a positive intent to harvest. This was evenly divided between different nonresident owners of property formerly held by a nonresident and different nonresident owners of property formerly owned by a resident. This is an indication that when resident-held property shifts to a nonresident status, the timber may still be available for harvest.

Attitudes and intentions are one thing, positive actions are something else. We found that eleven ownerships whose owners said harvesting was definitely incompatible with other objectives in 1967 had harvested timber by 1979. Two were the same owners, the rest were different. Five said they cut because they needed the money. In addition, three inactive ownerships (unsettled estates), whose owners indicated their timber was unavailable in 1967, had different owners in 1979 who had harvested. Quite obviously from this sample different owners are important as timber harveting prospects and perhaps in making timber available for harvest.

In analyzing the period between 1960 and 1967, Stone also reported that a significant proportion of owners who had no commercial timber objectives in 1960 subsequently had timber sales by 1967. The proportion increased as size of ownership increased.

Turner, Finley, and Kingsley (1977) found a similar situation in Delaware--that there was considerable change in attitude or action after only four years. They concluded that owners of small tracts--often too small for practical harvesting--are the ones who consistently oppose harvesting and they control a relatively small proportion of the State's timber.

We conclude, as did Stone in 1970, that most timber on NIPF owernships will likely be available in the long run. Certainly all indications are that whole tree thinning could assure this availability and provide increased growth, quality, and value of the hardwood forest resource as well.

We feel that the results of these studies have important implications for timber supply in the Lake States if not for the Nation. Certainly, when an assessment for industrial development projects include an estimate of timber available from NIPF ownerships, the amount available may be much larger, especially in the long run, than previously thought.

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SUMMARY OF HARDWOOD THINNING SYMPOSIUM

Craig Locey[1/]

We have seen examples of what Hank Webster discussed in terms of increased attention on hardwoods in the Lake States, so it is more than fantasizing. We are beginning to see some of these things take place.

The overview we had on some of the pros and cons of silviculture and the comparison of even-age and all-age management, the importance of residual stand density in maintaining quality, and some of the thinning systems are all viable options. We can all relate to our own individual experiences and see where they are beginning to pay off. The fascinating part is that we now are beginning to see economic opportunities to accomplish cultural activities that we all knew should be done, but were economically very difficult to accomplish in the past. To me, it is seeing the light at the end of the tunnel; I believe we are on the threshold of some dramatic changes.

In relation to the discussions we had on damage to residual stands, I have concerns. When we are trying to assess the damage from mechanized processes, I would like to put more emphasis on Alex Shigo's work and see if it is feasible or practical to be able to tolerate a slightly higher percentage of damage of small-diameter stems. Shigo, through his work on compartmentalization of decay and damage to larger diameter stems, really focused on the high economic impact this potential damage may have on the stand. This may be a subject area that needs much more attention.

Relating to Carl Trettin's presentation on soil compaction, it made me question somewhat some of the recommendations we have talked about. One was to encourage skidding operations to spread out over the entire sale area and not concentrate in skid trails. The reason for that was to increase scarification, but with the dramatic impact on soil compaction and its slow recovery rate, I question if that is a wise decision. It is something we must think about.

I appreciate Dick Bierlich's industrial perspective. I work for a public agency, and I am envious of a person who can follow the entire process through from beginning to end and have "total control." That is a real opportunity!

Regarding the economics of early thinning, I will have to admit that I am somewhat skeptical. We have heard profitable statements come from many different directions, so I am inclined to think that Gerald Thiede's opinion is right regarding early thinning as a good investment.

I have a low budget woodworking hobby at home. I didn't realize it, but after listening to Ed Kallio, I found that I have been using the "System 6 process" for quite a few years!

1/Timber Management Specialist, Wisconsin Department of Natural Resources, Tomahawk, Wisconsin.

I appreciate all of the viewpoints of the members of the panel on forest management perspectives. It is interesting to compare these and the problems that are unique to each viewpoint. We are involved in managing public land in terms of multiple use and integrated resource management, and we share Myron Smith's concern. In reality, we should apply the same logic to private ownership. We have just heard about the high percentage of our hardwoods that are in small private ownership and as professional foresters, I believe we can increase management on these lands through intelligent integrated resource management. Many small landowners place more value on wildlife habitat, recreation, etc., than timber production. It is our responsibility to show how silvicultural practices can be the tool to accomplish their goal. Plant succession continues in these stands, and if they aren't managed, they may succession into a habitat stage that may not provide the landowner's management objective. It is a sales program on our part.

Jim Halvorson mentioned some things on contract specifications. That is another basic criteria to accomplish desired objectives.

To get back to Dick Bierlich, you could see there is very tight sales administration on their company lands.

With reference to Lloyd Casey and the fuelwood situation alone, that was the beginning of quite a dramatic change in making TSI operations economical. It will allow us to accomplish activities that were economically impractical in the past. We have a State Forest just a few miles west of Milwaukee. Intense competition for fuelwood in such areas has generated unusually high fuelwood prices.

From the size of the turnout for this program and the fact that attendance and attention has remained high right through the last session, I think we can conclude that it has been a timely and well presented agenda.

CTL:nll

SESSION IV - DISCUSSION

Q1. I believe Jim Halvorson brought up a question for Jerry Thiede when he talked about the very labor intensive nature of TSI marking. Jim indicated that a forester can mark an acre to an acre-and-a-half per hour or 10 acres per day. If manpower is all benefits and transportation is worth $200 a day, you are looking at a cost of $20 an acre. Thinking back to what Jerry said about the State being a no-cost effort now on TSI, I wonder if that included roughly $20 an acre just to mark the stand, much less to have it cut? Would someone on the panel wish to comment on this--Jim Halvorson or anybody that might speak for the State of Michigan?

(Moderator Gaffney) The question refers to an earlier speaker who indicated that the cost of marking is approximately $20 an acre, and he is asking the panel for comments on it. Jim, would you have any idea of what your cost per acre is on marking?

A1. (Halvorson) The cost is actually paid by the taxpayers; it is not passed on to the private landowner or to the County forests, per se. I really do not know. Twenty dollars per acre, that's what you're saying, right?

(Locke) You followed my example, didn't you? If you can mark only 10 acres in a TSI-type marking in a day, then personnel time, whether it is $150 or $200, will amount to $15 to $20 per acre for marking. I am assuming it costs about $20 an acre to do the cutting. I do not think it is exactly a no-cost deal. I do not know if Jerry Thiede is still here to defend himself on that subject. But to me it is not a no-cost deal. There are tremendous costs just in marking.

Q2. Jim, you had some forester productivity data, didn't you, in your earlier trials of marking hardwood thinning sales?

A2. (Halvorson) Those are the figures I quoted. For marked selection, it came out to about an acre or an acre-and-a-half per hour that could be marked. For the strip selection or the strip cut, that came to about 2-1/2 acres per hour--again, based on six to seven cords to the acre. The marked selection between the strips was the most productive from a forestry standpoint; one forester could mark about 3-1/2 to 4 acres per hour. There is a cost there, but I do not really know how to answer your question. We do not figure it in.

(Moderator Gaffney) Jerry Thiede is not here to defend the statistics, so we cannot sufficiently answer that question.

Q3. Most of us are familiar with the work that Dr. Shigo did, which indicated that a good share of our defect, degrade, and discoloration in hardwoods comes from an injury to the tree. A good share of the injury on these trees is from logging. We have been talking in terms of anywhere from 7, 10, or 12 years as a cutting cycle. Why don't we lengthen the cutting cycle? We know how far down in basal area we can go and still maintain quality in the stems. If we can lengthen our cutting cycle to 15 years and assume 90 years as the rotation age of the tree, we would decrease

the number of times we enter that stand by about 33 percent. In addition to saving time for marking and preparing the sales, we could cut out a little more basal area and give more room for skidding and therefore cause less damage.

(Moderator Gaffney) Would anyone care to comment on the feasibility of reducing defects by lengthening the cutting cycle?

A3. (Halvorson) That is a very good point. I agree with you 100 percent. Normally, foresters mark too light rather than too heavy. It is something to consider.

(Moderator Gaffney) Any other comments? I believe marking is most often governed by the growth rate, and much of the work that I have done in the past has shown that 15 to 20 years will give sufficient growth to be able to continue the cutting cycle. It varies by area, the stocking there is to work with, and the economics of the time.

Q4. Mr. Carpenter, has any research been done to determine how much of the wood coming from these private lands is from lands that are being mined rather than managed?

A4. (Carpenter) No, I am sorry, we do not. The study that we did, which is tied in with the statewide forest survey on a plot basis, does not give us those answers. One would guess, though, that if they are cutting--if their tendency is to maintain a low volume of material or a low timber capital because of their high time preference for money--that some of this could occur, but I do not know how much.

Q5. A question to Mr. Connor. I do not know how much basswood you have in that part of the State, but you indicate a considerable amount. I do not know if anybody has ever tried this before, but it is a thought. Basswood holds its taper very well and dries out probably light. If treated, could it possibly be used for cabin logs?

A5. (Connor) I cannot answer that question. I do not think that it would make a good cabin log, although I think we have to try to find some way to get the bark off in the woods. What you are suggesting is that we take it off in the woods in some way. We do not seem to be able to get it off at the plant. Either it comes off in one big piece which plugs all our conveyors, or if it does come off in small pieces, it threads up in the conveyor or the debarking heads. We recently had a situation at Goodman where we finally had to discontinue debarking the basswood sawlogs. It just throttled the debarker head down to the point where it could not operate. So what you suggest may be feasible--some method to get the bark off in the woods.

(Halvorson) In answering that question, it is not rumor that there is a very good possibility that basswood can be cut into cants and used as landscape timber. I believe there is a fellow who has done research on this. I cannot remember where he is located. In fact, he has approached our County and questioned what our supply could possibly be.

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5. Mr. Connor, do you have any comments on the viability of the System 6 method for utilizing small hardwood logs?

6. (Connor) Unfortunately, I was not here for that presentation, and I know very little about System 6 techniques. I will have to turn this over to somebody else on the panel who was here for that discussion.

(Moderator Gaffney) Does anyone else wish to comment on this? The question was directed to Mr. Connor asking him, as a sawmill owner, whether he thinks the System 6 method could benefit him in his operation.

(Smith) I suspect you will find that is a specialty type thing. You would have to set up a mill for that based on what we heard this morning, and it probably would not fit in with the system that most sawmillers have today. I think it would take a fairly good investment to set up for it.

(Connor) In the old Conner Forest Industries mill in Laona, they had a technique that utilized the slabs and edgings that developed from the production of high-grade sawlogs. The slabs and edgings were ripped and put through a "pony" resaw, ripped to width, and used very successfully in the furniture production at Laona. I think Steiger Lumber Company also developed a system similar to this System 6. I am referring to a pamphlet on the System 6 that Myron Smith just gave me. They did not take the trim nor debark their low-grade lumber in the mill; they used the low-grade lumber that was undebarked to produce dimension. Paul Steiger always felt that the only profit he ever made making dimension was in making it from the edgings that would have normally been thrown away, which is very similar to this system.

7. Mr. Carpenter, do I understand that you feel that the private land will contribute to the long-range timber supply? Do you have studies in other states that verify the same things that you found in Michigan?

7. (Carpenter) I think our study is the only one that looks at three time periods. The other studies that I mentioned, Bob Stone's study and the Thurner, Fingley, Kingsley study in Delaware, looked at two time periods. I do not think anyone else has addressed that specific problem. I do know that more and more people are accepting it. There was a fellow from Texas who addressed an audience at a meeting in Duluth a couple years ago. He had drawn the same conclusion that this volatile ownership and change generally means that, over a rotation, a great deal of this nonindustrial private forest land will be available for harvest.

When you consider that 72 percent of the land in the Northeast Area is owned by private ownership, and only 6 percent is National Forests, it has to come from there.

U.S. Department of Agriculture, Forest Service. Sturos, John A., comp. Hardwood thinning opportunities in the Lake States. Gen. Tech. Rep. NC-113. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 153 p.

The symposium presents and discusses new information on the hardwood resource, silviculture, harvesting, economics, and product potential from hardwood thinnings in the Lake States. Included are forest management perspectives from the logger, private industry, and state and federal forest managers.

KEY WORDS: Hardwood resource, silviculture, harvesting, economics, wood products, forest management.

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Achieving Wood Energy Potentials: Evidence in Northeastern Minnesota



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ACHIEVING WOOD ENERGY POTENTIALS: EVIDENCE IN NORTHEASTERN MINNESOTA

COMPILED BY:

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Duluth, Minnesota

FOREWORD

Few doubt the continued significance of wood energy development in the United States, but its precise role in forest management is still unclear. Existing forest products firms are understandably concerned about how expanding wood energy use will affect their raw material costs. Others, convinced of the short-term silvicultural advantages of harvesting wood for energy, are concerned about long-term effects.

The following papers describe a novel integrated approach to assessing wood energy potential in northeastern Minnesota. They represent a significant cooperative effort funded with Energy Security Act monies through the USDA Forest Service. More than 14 scientists and their staffs applied their skills in economics, silviculture, biometry, engineering, forest policy, and mathematics over a 3-year period. Three similar studies were done in other regions.

In the North Central region, we found that wood energy would have more than just a short-term silvicultural advantage. Besides pointing out the significant positive economic impacts on regional employment and fuel cost savings, our study illustrated the usually obscure economic interactions between various wood energy demand scenarios and the long-term costs of all wood products. If long-term forest productivity is important, more rapid wood energy development is a realistic way to achieve it.

Due at least in part to this effort and previous work by the North Central Forest Experiment Station and our cooperators, we can better understand the consequences of wood energy development.

CONTENTS

Page

WOOD ENERGY POTENTIALS IN NORTHEASTERN MINNESOTA
Dennis P. Bradley 1

PREDICTING MULTIPRODUCT TIMBER YIELD FOR LONG-TERM SUPPLY ANALYSES
Alan R. Ek, Howard M. Hoganson, and Jerold T. Hahn 6

IMPACTS OF WOOD ENERGY USE ON TIMBER SUPPLY IN NORTHEASTERN MINNESOTA
Howard M. Hoganson 13

AN ASSESSMENT OF PRODUCTIVITY AND HARVESTING COSTS FOR VARIOUS FOREST HARVEST SYSTEMS
Robert A. Hazenstab, Jim L. Bowyer, Dennis P. Bradley, and Howard M. Hoganson 31

FUTURE MARKET UNCERTAINTY: A CASE FOR SHORT-ROTATION SYSTEMS
Howard M. Hoganson, David C. Lothner, and Paul A. Rubin 38

ESTIMATING WOOD ENERGY DEMAND IN NORTHEASTERN MINNESOTA
Dennis P. Bradley and John S. Gephart 44

ECONOMIC IMPACT OF SUBSTITUTING LOCAL WOOD ENERGY FOR IMPORTED FOSSIL FUELS
Richard W. Lichty, Dennis P. Bradley, and David J. McMillan 60

POLICY OPTIONS TO ENCOURAGE WOOD ENERGY USE IN NORTHERN MINNESOTA
Paul V. Ellefson, Andrew M. Wheatcraft, and Dennis P. Bradley 66

ENGINEERING AND ECONOMIC CONSIDERATIONS OF WOOD ENERGY SYSTEMS USING WOOD CHIPS AND PELLETS
Philip G. Steklenski and John G. Haygreen 77

WOOD ENERGY POTENTIALS IN NORTHEASTERN MINNESOTA

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Minnesota has one of the highest per capita energy
s in the Nation and has no coal, oil, or natural gas.
it has vast, underused forests that could meet a
nificant portion of its energy requirements. A com-
hensive study of the situation in northeastern Min-
ota is now complete. This study:

examined the short- and long-run impact of in-
creased wood energy use on the supply costs of all
forest products;

estimated current markets for industrial, commer-
cial, institutional, and residential energy;

estimated the potential economic and social impact
of increased wood energy use by various sectors;

identified alternative public policies to stimulate
greater wood fuel harvest from Federal, State,
County and private land;

identified barriers limiting the use of wood fuels; and

facilitated efforts among loggers, forest managers,
energy users, equipment suppliers, environmental
agencies, and regional development agencies to pro-
vide for an efficient and equitable transition to in-
creased wood energy use.

This was an interdisciplinary cooperative effort that
luded the Economics and Forest Survey Projects,
rth Central Forest Experiment Station; the College
Forestry, University of Minnesota, St. Paul; the Bu-
u of Business and Economics, University of Minne-
a, Duluth; and a St. Paul Engineering Consultant.
nding for this research came from the Boundary
ters Canoe Area Wilderness Act of 1978 and the
ergy Security Act.

BACKGROUND

The study area consisted of about 11.5 million acres
he following seven counties of northeastern Min-
ota: Aitkin, Carlton, Cook, Itasca, Koochiching,
Lake and St. Louis. About 7.4 million acres or 65 per-
cent of the total is commercial forest land and it differs
widely by cover type and owner. Public forest land
comprises about two-thirds of the study area; 23 per-
cent is federal, 21 percent is state, 22 percent is county,
10 percent is forest industry, and 24 percent is other
private.

Hardwood cover types comprise 60 percent and soft-
wood cover types comprise 40 percent of the total.
Aspen and paper birch types cover 60 percent and 17
percent of the hardwood area, respectively, and balsam
fir/white spruce types occupy 31 percent and 33 percent
of the softwood area, respectively. But even this view
is confounded because almost all cover types are
heavily mixed with hardwood and softwood species.
The major concern, as well as current opportunity, is
that more than half of the aspen, paper birch, and
balsam fir/white spruce types exceeds 40 years of age.

Previous efforts to characterize industrial opportu-
nities for this wood have often emphasized ratios of
growth to removals. One recent attempt using this ap-
proach found that total annual net growth of all species
in the area was about 115 million cubic feet per year
compared to estimated annual removals of about 77
million cubic feet. This leaves an annual surplus of about
38 million cubic feet. Presumably, increased harvests
would reduce this current surplus as well as future
opportunities.

However, mortality in this area was roughly 56 mil-
lion cubic feet, due in large part to the rapidly maturing
or already over-mature forests. Gross growth was 171
million cubic feet (49 percent) greater than net growth.
If these trees would have been harvested before they
died, the surplus would have been about three times
greater or 94 million cubic feet. The point is, under
current age class conditions, expanded, not reduced,
harvests are needed. Growth to removals ratios are
relevant only for a managed or regulated forest with an
even age class distribution. Clearly, northeastern Min-
nesota's forests do not meet these criteria.

Biological opportunities are not the same as economic supply. Simply having a large inventory or the prospect of an even larger one in the future doesn't mean that we should or even could use it. Stand location and access to market, site index, existing stocking, species mixtures, harvest costs, and government regulations all interact to determine economic harvest levels. So, too, a "surplus" cannot be harvested independently of what is already used. Many of the economies of recovering currently unused wood will take place only if we can harvest it along with traditional saw logs or pulpwood. This study focused on timber supply in this broader economic perspective.

Throughout this report, we avoid the term "residue" and refer instead to "wood energy" for two reasons. First, "residue" often carries a negative connotation. Second, the term often only includes branches and tops, bark, cull logs, etc. "Wood energy" also includes all those trees and stands for which no current market exists. Some of these trees may even meet the highest quality standards. Although we do not wish to appear as wood energy advocates, our analysis suggests that any other large utilization opportunity for much of this poor quality material currently is highly unlikely. In the longer run, other more valuable product opportunities may develop. At that time, any use that can return the largest social and economic impact is to be preferred.

MAJOR FINDINGS

We conclude *first*, that northeastern Minnesota's forest resource could supply significantly more wood to an energy market without greatly increasing the cost of other forest products.

Second, harvesting more stands in the next 20 years would enhance future forest productivity; older, slower growing, under-stocked stands would be replaced by younger, faster growing, fully stocked ones.

Third, using more of this wood for local or regional energy needs would reduce regional energy costs, increase total regional output of all goods and services, and increase regional employment. These are critical concerns in northeastern Minnesota.

Fourth, many existing barriers to increasing the use of wood for energy can be removed at low cost by modifying current attitudes and policies that govern forest management. Wood energy is a valid use that is not inferior to sawtimber and pulpwood. Policies can be developed to allow wood energy or any other potential use to compete on its own merits.

MAJOR TASKS

Simulating Future Wood Supply

The pulp and paper industry currently is the largest wood user in northeastern Minnesota, but the waferboard industry recently has expanded significantly. Both use primarily aspen, a species that is currently abundant. Projected increases in demand for aspen raise concern about its future supply. Several studies addressing this type's unbalanced, economically and biologically over-mature condition, suggest that significant shortages will occur in 20 to 50 years if current harvest trends continue. As we shall show, developing wood energy can improve long-term wood supply in general and aspen supply specifically. In other words, it can reduce future wood costs.

Current forest conditions result from past actions. The region's forests, first logged in the early 1900's, regenerated naturally to mostly even-aged mixed hardwood and conifer stands, rather than to the original, mostly pure conifer types. These species mixtures dramatically affect stand values; prices for standing timber can differ by a factor of 10 due often to the presence of unwanted species. If significant portions of a stand are unsalable, a harvest is not usually economical. Unwanted species also hinder regeneration as well as occupy sites that could produce more valuable species.

How would a large wood energy market affect existing timber markets? Two potential complementary impacts are possible. In the short run, an energy market using unwanted timber could make previously uneconomic mixed stands profitable to harvest. In the long run, removing these previously unwanted or uneconomic stands could allow rapidly growing desirable stands to be established for expected larger future needs.

But other factors must be considered for their competitive impact. For example, the locations of wood energy markets often differ from those of ordinary timber markets. Because transport costs are often more than half delivered costs, a stand's location might result in all its' wood being sent to an energy market rather than being shipped to other markets. Similarly, small volumes of more valuable trees may be chipped for energy, simply because sorting wouldn't pay even if its transport would. Of course, these are serious concerns for existing forest industry.

In the past, foresters assumed that demand would increase so rapidly that they would never be able to

produce more than people wanted. Therefore, all stands, regardless of productivity or location, would be needed in a not-too-distant future. In order to meet this ever-increasing demand projection, harvest scheduling attempted to take the unregulated forest (with its unbalanced age distribution and widely differing annual outputs) and move it toward a more uniform and generally, maximum sustainable annual harvest level—so-called "even flow".

However, although most forests are unregulated, regulating them is now perceived to be less important. This is true partly because wood demand has grown only modestly and will probably continue to do so. If we are growing more wood than we can use, all land may not deserve continued investment. And if this is true, management opportunities must be ranked.

In this study we applied a new, more realistic harvesting scheduling model to all land in northeastern Minnesota to estimate the marginal costs of major product groups at various long-term saw log, pulp, and wood energy production levels. We estimated several future "desired" harvest schedules, identified the management alternatives and costs for each cover type, and chose the set of management alternatives that minimized production costs. We then examined marginal costs for each desired harvest schedule. These marginal costs help estimate the total cost incurred to achieve these outputs. In other words, they estimate what people would have to pay in order for the assumed timber investments to be profitable. Of special importance, we examined how the marginal costs of traditional forest products and wood energy interact.

This approach, recently developed by Howard Hoganson and Dietmar Rose, refines previous work on harvest scheduling and takes advantage of the special character of harvest scheduling problems. Briefly, the method is a simulation based on an economic interpretation of the key "dual" variables of a linear programming formulation of the harvest scheduling problem. These key dual variables or marginal costs are interpreted as the "shadow prices" of producing each product in each period.

Timber management scheduling problems rapidly increase in size as more stand information is included. Because a linear programming (LP) solution to these problems requires an exact optimum solution and because there is no way to know before hand when you are "close" to the solution, practical limits on computer time have often restricted the number of stand types to less than 400. The new process accepts near-feasible solutions. Not only is costly computer time saved by not looking for absurdly precise solutions, but also dynamic programming allows larger, more realistic problems to be considered. More than 6,000 stand types were considered in this study.

We used this new model to estimate the costs of meeting several different future wood output scenarios. We looked at future consumption levels for aspen roundwood and softwood roundwood ranging from their current levels of 5.5 and 4.0 million cunits per decade to 9.0 and 8.0 million cunits per decade, respectively. We also examined wood energy output levels from 1 to 30 million dry tons per decade.

Can northeastern Minnesota's forest resource meet these various demands? The question cannot be answered by a simple yes or no but instead can be answered in terms of cost. As Hoganson's paper shows, we have the wood now but unless we start using more of it soon, meeting future needs will be increasingly costly.

Under all future demand scenarios, aspen costs will rise in the next 20 to 30 years. This increase will occur regardless of future harvest level. The crucial point to make, however, is the effect of expanded harvest levels now on aspen costs after this 20-year period. Without expanding harvests now and in the future, costs must rise. That is, cutting more now would reduce future wood costs.

Simulating Fossil and Wood Energy Demand

Bradley and Gephart used a regional input/output model of the same seven-county area to measure the nature of current energy use. The input/output model for the study area, base line 1977, identified 215 sectors and their purchases of coal, petroleum, and natural gas. However, most of the fuel was consumed in only 31 of these sectors, so the remaining sectors were ignored. Using a micro-computer spread sheet, wood requirements and cost savings for several levels of fossil to wood fuel conversions were then estimated. These conversions were then used to create a new wood energy sector for Richard Lichty's analysis of regional economic impact, reported below.

Total fossil fuel use was about $280 million in 1977 (11 percent coal, 61 percent petroleum, and 28 percent natural gas). This does not include transportation fuel costs. The largest fuel users were iron mining, 16 percent; forest industries, 10 percent; petroleum refining, 9 percent; electric utility, 13 percent; gas utility, 8 percent; and households, 19 percent. We felt that the most likely conversion opportunity was judged to be the iron mining, forest industry, and electric utility's use of coal, which accounted for 87 percent of total coal use and 10 percent of all fossil fuel use. It was assumed that about 1/3 of the coal could be replaced by about 1.6 million green tons of wood per year.

The next most likely conversion opportunity was that several sectors' could replace fuel oil with wood for heating and processing. Major sectors assumed to convert would be forest industries, retail trade, health services, government, and households. These sectors used about 50 percent of total fuel oil and 32 percent of all fossil fuel. It was assumed that about 24 percent of fuel oil could be converted to about 1.965 million green tons of wood per year.

A third conversion opportunity would be natural gas also used for heating and processing. Major natural gas converting sectors would be electric utilities, wholesale and retail trade, health services, households, and government. These sectors used about 34 percent of total natural gas and 9 percent of total fossil fuel. It was assumed that about 17 percent of natural gas would be replaced by about 1.162 million green tons of wood per year.

In total then, about 25 percent of all fossil fuels would be replaced by about 4.743 million green tons of wood per year.

How this conversion would be accomplished remains to be seen. Current prices for both fuel oil and natural gas already favor wood (excluding conversion costs). However, coal prices are still lower than those for wood, even though coal conversion would cost the least. Thus, other factors must play a more important role if these conversions are to take place.

Regional Economic Impacts of Wood Energy Development

Using wood for energy probably complements forest industry at the levels assumed above in both the short and long run, but what about the socio-economic impact of such conversions? Using the same input/output model and the above wood energy demand scenarios, Richard Lichty developed new transaction tables including the smaller fossil fuel purchases and larger wood fuel purchases and then inverted them to estimate direct and indirect effects on (1) increased regional employment, (2) increased regional output, (3) fuel cost savings, and (4) induced impacts.

1. *Increased employment.* Under either scenario about 2,000 new jobs would be created, a 1.5 percent increase. About 400 of these would occur directly in the Wood Energy sector. These job increases are not as large as expected but seem reasonable considering the large under-employment in forest harvesting.

2. *Increased output.* Regional output would increase about $100 million in 1977 prices, a 2.0 percent increase. About $50 million of this increase would occur directly in the wood energy area. Here again the 2.0 percent gain in total output compared to only a 1.5 percent gain in total employment is additional evidence of the under-employment characteristic of much of this area's logging and wood transport industries.

3. *Fuel cost savings.* Fuel cost savings would be about $15 million in 1977 prices, about 5 percent of total fuel costs. However assuming 1980 price differentials, this would be about $55 million or 10 percent of total fuel costs.

4. *Induced impacts.* Although the input/output model used could not show it, fuel cost savings would induce added regional growth in output and employment because these dollars would be available to be spent for other things.

Barriers to Wood Energy Development

An important barrier to conversion arises out of traditional concerns about wood supply. Wood consumers must depend on resource professionals for answers. However, the messages conveyed by them have been contradictory. Nationwide, some forestry agencies continue to raise the traditional spectre of rising wood prices and large shortages for as long as they care to project. Others have identified dramatic surpluses in many regions of the U.S.

On the whole, most land management agencies, have taken the traditional view and have not dealt with the contradictions inherent in more specific resource analyses. Resolving the technical questions of shortage vs. surplus in realistic regional analyses is an important step in addressing what we feel is a nationwide problem of unnecessarily low wood utilization.

Another key obstacle to addressing wood energy development in particular and poor wood utilization in general have been many agencies' negative attitudes towards wood energy or any other nontraditional, presumably inferior use. Resource professionals must be more neutral to wood use opportunities. Any use that can compete in a free market should be welcomed. Of course, we cannot expect existing wood using firms to embrace potential threats to their wood supplies of long standing. However, it should be possible to avoid the "we vs. they" issues and concentrate on real and solvable aspects of this problem.

Ellefson *et al.* outlined an extensive list of programs and policies that could encourage wood energy specifically and wood utilization generally. These policies were also rated on the basis of several criteria but were not ranked. It seems that the technical and financial obstacles are being addressed and that government at any level is poorly equipped to deal with them anyway.

However, regulatory and administrative perspectives, often based on traditional but arbitrary rationales, are fertile grounds for change.

Policy Recommendations

Wood energy development will require a host of individual actions by entrepreneurs as well as concerted action by agencies. Considering the preponderence of public land in northeast Minnesota and our previous discussion of barriers, it seems logical to expect most of the critical initiatives to come from the County, State, and Federal land managers in the region. The major question is wood supply! All other issues and policies depend on how wood energy is viewed to fit into the total wood supply picture. If supply is really tight and real prices for saw logs and pulpwood exceed wood energy, or are expected to do so soon, then timber sale and pricing policies should probably parallel current practices.

However, we feel that a long-term view of the forest situation in northeast Minnesota shows (1) a large resource surplus, as evidenced by both real price declines and expanding inventory; (2) a large economically overmature age class imbalance with a corresponding high mortality; (3) the imminent "loss" of money already spent to grow and protect this large surplus during the last 60 years unless a great deal more is used soon; and (4) even higher future wood costs due to the lost opportunity to use now and thereby set the stage for enhanced forest output later.

Given a large, current, short-lived surplus, and the chance to enhance future output at lower costs, all those attitudes and resulting policies that arbitrarily obstruct wood utilization must be changed. For public and private forest resources to play a larger role in economic development, forest policies must reflect the economic realities. Surely, current ones do not. Primary forest production and primary forest industry in northeastern Minnesota are not competitive in an economic sense. There are at most, a dozen or so wood buyers and no more than half as many significant wood growers. This situation is more characteristic of the U.S. energy industry than U.S. agriculture, yet agricultural pricing and marketing policy models are used.

Instead of trying to sell a few cords or board feet of wood at a time, larger, long-term sale and pricing agreements could be considered. Exclusive and long-term coal, oil, and gas leases on public and private land are negotiated based on the economic reality that little investment will occur without them. Similar marketing policies are needed for wood, too. Such radical changes would require overcoming some significant political obstacles, and other less dramatic ways may accomplish the same thing. But existing forest industries must be given opportunities to help formulate these policies. If northeastern Minnesota's wood-using opportunities have a time limit, existing firms could be given right-of-first-refusal on the use of much of the surplus. Surely no one would lightly propose losing two jobs to gain one, even if the change resulted in increased value added. However, if those options are refused, it would seem to be the public land manager's responsibility to seek firms who will.

SUMMARY

This study of the effects of wood energy development shows what could exist, not necessarily what should exist, in northeastern Minnesota. Results indicated that the impact of increased wood energy use would be largely complementary to traditional forest industry. The mechanism is simple: in the short run, a wood energy market would reduce the variable costs of all wood products by enabling many previously inoperable stands to be harvested profitably. In the long run, wood energy markets would lower fixed and variable costs of all wood products because slow-growing, overmature, poorly stocked areas would be replaced by well-stocked, rapidly growing stands.

Northeastern Minnesota is currently a hotbed of changing forest resource management perspectives. Each of the three major public agencies are seeking opportunities to address their budget limitations, improve wood utilization, respond to regional economic growth initiatives, and provide greater socio-economic rationales for their programs. Wood energy development is attracting a lot of interest. Our findings, especially on the critical interactions between current wood energy development and future supplies of traditional sawtimber and pulpwood, should provide viable alternatives for land managers.

PREDICTING MULTIPRODUCT TIMBER YIELD FOR LONG-TERM SUPPLY ANALYSES[1]

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Basic forest management concepts such as sustained yield, allowable cut, and even flow are all based on long-range supply analysis. Each National Forest in the United States is required by law (National Forest Management Act of 1976) to examine the long-term timber supply in its overall forest management planning process. Other Federal land management agencies also employ long-range supply analyses as an integral part of forest management, as do many State, county, and private landowners.

The slow growth of most timber species makes long-range planning especially important. Long-term production can be strongly affected by harvest cycle and harvest technique. The decisionmaking process must include not only the direct costs and benefits from initial harvest, but also the impacts of today's harvest on future timber supplies. This complicates the manager's problem of selecting a harvest quantity and species mix, especially for mixed-species forests that rely heavily on natural regeneration.

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With the advent of the computer and development of timber harvest scheduling models, comprehensive long-range supply analyses (Jameson *et al.* 1982) are now possible. But unfortunately, it has not been easy to assemble, for a large region, precise and accurate yield estimates for numerous potential products by species and stand treatment alternatives for many different stand types. The number of distinct stand types can be very large, because age, density level, site quality, and species mix all influence tree growth and product yield. Attempts to assemble this information have also been frustrated by the fragmented results of growth and yield studies, by prediction models that address only a few species or cover types, and by incompatibility among models in terms of inputs and outputs. Further, existing multispecies models are still far too slow and costly in execution to be utilized as subprograms called by optimization algorithms that must examine many alternatives. This paper addresses these problems by describing a practical procedure for developing multiproduct yield estimates. The yield tables and estimation procedure, which are currently being used as the basis for several long-term analyses, illustrate techniques that can be applied widely in forest management planning.

INFORMATION NEEDED FOR TIMBER SUPPLY ANALYSES

The procedure described here evolved from attempts to develop growth and yield information for northeast-

ern Minnesota to assess the impact of alternative short-run harvest opportunities on the long-run timber supply. Growth and yield data from this region have been published in a variety of forms for a number of species over the last 60 years (see Ek and Brodie (1975) and Schlaegel (1971) for aspen; Buckman (1962) and Lundgren (1981) for red pine; Benzie (1977) for jack pine). Unfortunately, the various growth and yield tables or models described in these and similar reports do not cover all of the pure and mixed-species stand conditions of interest nor do they provide much detail on growth response to varying stand densities.

Consider, for example, stands that fall into the aspen cover type, a major cover type in northeastern Minnesota. Many aspen stands contain significant volumes of other species; in fact, this "other" component can be the major value component of the stand. Two aspen stands might each contain 24 cords of aspen per acre, but one might contain an additional 6 cords per acre of birch while the other contains 6 cords of a softwood species. In terms of northeastern Minnesota prices for timber sold on the stump, aspen is selling for approximately $2 per cord, while birch is selling for less than that. Softwoods, however, could easily return $25 or more per cord depending on species and tree size. Based on these values, timber harvest returns from the first stand would total less than $60 per acre, while those from the second would be approximately $200 per acre—over three times as much. From a financial viewpoint it is clear that these are two different stand types, yet available growth and yield models lump stands like these together, and give little if any detail on species breakdown. Further, with most models, inputs differ and outputs are limited in terms of the number and type of products.

Conducting supply analyses with conventional growth and yield information requires either the collection of additional data or a method of synthesizing existing data. Time and cost constraints dictate a focus on the latter alternative. Desirable characteristics of the needed growth and yield estimation approach are that it be:

1. Capable of projecting yields for any age of possible final harvest.
2. Compatible with harvest scheduling models to the extent that it does not further complicate the scheduling process or unnecessarily increase its cost.
3. Detailed in terms of yields for a wide variety of tree product breakdowns by species.
4. Sensitive in terms of the relationship of growth to stand density, site quality, and species composition.
5. Smooth with respect to growth and yield patterns both in terms of total volume yield and for species breakdowns.
6. Easily and rapidly accessible by computer.

Smooth growth and yield curves are desired because optimization techniques used in the scheduling process cannot always filter out irregularities or random variation. Scheduling models treat all inputs as knowns and thus irregularities in growth and yield curves can significantly affect scheduling results.

Recently, a large number of individual tree-based stand growth projection models have been developed that can provide detailed growth and yield information for a wide variety of stand conditions. These models are generally accurate for short-run projections, but they are not well tested and accepted for projections beyond 20-30 years. Longer projections are very sensitive to the ingrowth and mortality components of the system and projection errors can be magnified over time. Furthermore, test data for longer periods are still limited. Consequently, the utility of these growth projection models for long-run timber supply analysis is questionable.

Another approach is to develop empirical yield tables (Husch *et al.* 1982) based on recent forest inventory plot information. This approach has limitations, however, in that past cultural and harvesting practices may preclude the possibility of these plots adequately representing all stand conditions for each age and site class. In fact, the small sample size for the recent inventory of northeastern Minnesota did not provide enough plots to develop detailed yield tables by age and site class for all of the cover types of interest (Hahn and Essex 1982).

COMBINING YIELD TABLES AND GROWTH MODEL PROJECTIONS

Our methodology overcomes some of the problems of empirical yield tables and growth projection models by combining the two approaches. By using a growth projection model, additional plot data points can be generated for developing more complete empirical yield tables. Using plot growth projections along with the original plot data adds serial correlation to the data, but this correlation also helps smooth the growth and yield curves. Also, the additional data points generated allow more detailed information on yields for some site-quality classes. For example, the existing stands that fall into older age classes tend to be of poorer (less harvestable) site quality or they are residual stands left after some partial harvest. Site quality influences growth and yield, but by using survey plots alone, it is often difficult to recognize site quality differences because data are often lacking for older-age, high site quality classes. This problem is overcome by the addition of observations developed from projections.

Our methodology evolved as three steps. STEMS, the Stand and Tree Evaluation and Modeling System

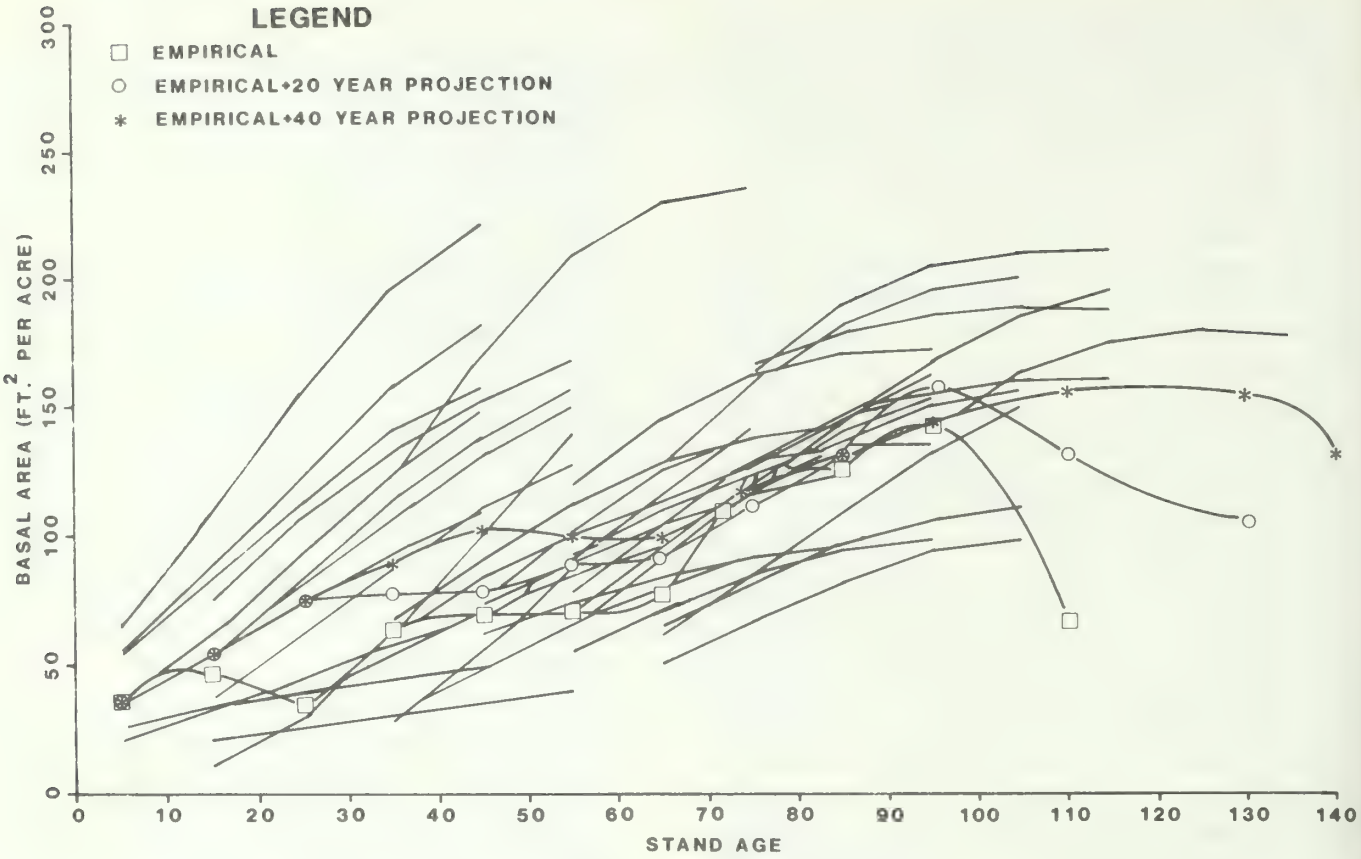


Figure 1.—*Basal area over age for* aspen with 10 percent or more pine (site index 0-65) *type by averaging option: empirical yield data; empirical yield data plus 20-year projections; empirical yield data plus 40-year projections. Fine lines represent projections of a systematic sample of plots. Heavy (smoothed) lines are based on graphics package algorithm and included for illustration only. Based on 79 plots.*

(Belcher 1981) was used for all growth and yield projections, and 4,567 inventory plots established during the 1976-1977 Minnesota inventory[3] (Jakes 1980) served as the basic data source. The STEMS projections were made using the deterministic mortality option in the model (Belcher *et al.* 1982).

The *first* step was to project the plots for 40 years to assess which plots were likely to change cover types. Relatively few of the plots, less than 5 percent, actually changed cover type definition as determined by a basal area-sorting algorithm. In practice, a handy wall-mounted cross tabulation of plot frequency by initial type and type after a 40-year projection was used in guiding these specifications. Based on these projections and the direction of cover type changes, some 43 species group and site class combinations were specified. Hereafter these combinations are called "types." The *second* step was development of type-specific empirical yield tables using only the survey plot (empirical) data. Within each type class, plot yields were averaged by 10-year age class. The *third* step was identical to the second step except the number of data points (plots) was increased significantly by including as data points the 10-year, the 20-year, the 30-year, and the 40-year STEMS projections for each plot. This step produced approximately smooth growth and yield curves in nearly all cases.[4] Curves for basal area are illustrated in figure 1, along with 40-year projections of a systematic sample of the individual survey plots. Note that the incorporation of projections tends to raise and smooth the basal area/age relationship. Plotting projection results suggests that either the projections are overestimating growth or that the older age empirical yields do not represent a real older stand growth series. However, some raising of the average would be expected because the projections generally do not incorporate the effect of catastrophic events such as blowdown, fire, land use changes, epidemics, etc.

[3] *Plots established by the Forest Inventory and Analysis Research Work Unit at the North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture.*

[4] *This step was also attempted with 30-year rather than 40-year projections, but the latter provided more satisfactory smoothing.*

Unfortunately, the actual magnitude of that effect is indeterminate at this time. It was the authors' judgment, however, that the combination of the projection and empirical yield data produced a more realistic estimate of the actual growth series than either data source by itself.

A *fourth* step for some cover types involved the further smoothing of the basal area versus age class relationship. Several smoothing approaches were examined, including polynomial models relating basal area to age, but the most satisfactory was simply

$$B_t = \frac{1}{4}\cdot[B_{t-1} + 2B_t + B_{t+1}]$$

where B is basal area and t is the age class.

APPLICATION PROCEDURE

The data combination and smoothing process is illustrated in figure 1. The results provided an average basal area for each of the 43 species group/site class types for each of 14 10-year age classes to age 140. Average stand yields for some of the corresponding merchantable products are shown in table 1. The various product outputs were developed by applying different tree volume and biomass equations (Hahn 1984) to the individual tree data for each plot. These yield tables are converted to an average yield per unit of basal area and adjusted to the smoothed basal area when the tables are accessed by the supply analysis model. The result is a set of rapidly accessed "look up" yield tables for each age class. The forest-wide species composition is in large part handled by the original species group/site class stratification. When a stand is harvested, it is replaced by the youngest age class corresponding to the species group it would likely become. In the case of artificial regeneration, the stand could be converted to a different species group.

Growth and yields for nonaverage stand conditions within a type can be developed in several ways. We assumed simple proportionality: the growth and yields of stands with basal areas differing from the smoothed average were considered to be higher and lower than the average according to the proportion their basal area was of the average. For example, a stand with 20 percent more basal area was assumed to have a 20 percent higher yield at that and subsequent ages. We also considered approaches which assume that stands grow towards some normal or full stocking level over time, but with the exception of the red and white pine type, there was insufficient evidence in the data to support these approaches.

VALIDATION AND EFFECTIVENESS OF THE APPROACH

Unlike those in figure 1, the red and white pine projections in figure 2 show definite upward crossing of the empirical yield curve. Such patterns were not evident for other species, perhaps in part due to infrequent thinning of those species and their limited response to thinning. Thus, the simple proportionality assumption noted above seemed to work well. Red and white pine, however, are known to respond to thinning at even advanced ages. Consequently, a variation in procedure for estimating basal area growth for this type would be to express it as a function of stand density or perhaps use the simple stand basal area growth equation developed by Buckman (1962).

As a caution to users, note that the yield table (table 1) is broken down to only four species groups. It is possible to partition these data to a finer level of species and product aggregation; however, the yield-over-age pattern becomes increasingly irregular when that is done. Thus, the approach may still have limitations for study of individual species in mixed species stands.

Users may also question the large average diameter for 11- 20-year-old stand given in table 1. However, it is important to recognize that this value represents a combination of young trees and residual stems following harvesting. It is the average of what was found in the inventory for this age, site, and type. It is thus a good estimate of what we might expect on the average, given recent management.

The above procedure is not mathematically or statistically elegant. However, it is effective in developing more realistic growth and yield information in a rapidly accessible form compatible with harvest scheduling models. It does provide some sensitivity to differing stand densities and varying species composition. It also provides simplicity in use and interpretation of the tables, both within the computer and for the analyst. As growth observations for long periods become more readily available, it will be appropriate to more rigorously test the validity of assumptions here and perhaps rely more heavily on projection models. Growth of volume by product and assumptions about species composition stability by strata are first priorities for testing.

At present there are few geographically extensive growth observations covering a long time period—and none in the study region. Despite this lack of observed

Table 1.--Average yield per acre and stand characteristics by selected age classes for Aspen with 10 percent or more pine (site index 0-65) type [1/]

Product class[2/]		Unit of measure	Age class (years) 11-20	31-40	51-60	71-80	91-100	121-140
Pine & spruce	GS	cubic feet	174.5	456.6	580.4	724.1	1,105.2	1,612.0
Pine & spruce	SL	cubic feet	116.1	348.0	412.0	569.2	907.5	1,353.5
Pine & spruce	US	cubic feet	31.5	70.4	73.9	106.5	164.5	206.4
Pine & spruce	AL	green tons	6.7	17.2	21.5	24.7	37.5	53.7
Softwoods	GS	cubic feet	49.4	127.5	161.3	219.9	292.8	121.5
Softwoods	SL	cubic feet	20.1	68.7	72.6	117.1	179.1	64.8
Softwoods	US	cubic feet	8.4	24.9	25.4	42.5	51.5	28.7
Softwoods	AL	green tons	2.7	6.2	7.2	9.9	12.6	3.9
Aspen	GS	cubic feet	251.2	514.6	573.4	772.0	954.4	678.3
Aspen	SL	cubic feet	110.6	254.2	335.5	563.9	776.5	583.7
Aspen	US	cubic feet	28.4	67.7	96.0	138.3	153.9	94.6
Aspen	AL	green tons	18.3	28.7	30.6	39.3	47.8	36.0
Hardwoods	GS	cubic feet	126.0	261.5	242.6	315.1	395.4	662.8
Hardwoods	SL	cubic feet	38.3	120.9	101.8	176.2	215.2	309.8
Hardwoods	US	cubic feet	13.6	43.0	31.1	53.9	58.8	99.2
Hardwoods	AL	green tons	9.0	15.8	17.1	20.9	24.4	40.8
Average diameter								
Softwoods		inches	9.4	12.5	13.2	13.7	15.8	15.2
Hardwoods		inches	6.4	8.4	8.3	10.0	12.2	13.0
All species		inches	6.8	9.0	9.1	10.5	12.9	14.2
Average basal area		square feet	55	90	100	119	144	156
Number of plots (actual)			11	9	12	7	1	0

1/ Raw, unsmoothed values from combination of actual plot yields with 40-year plot projection results.

2/ Definitions:
Pine & spruce = white and red pine and white spruce
Softwoods = other softwoods
Aspen = Bigtooth and quaking aspen
Hardwoods = other hardwoods
GS = growing stock trees $\geq$ 4.95 inches d.b.h. (see Jakes (1980) for tree class descriptions)
SL = Saw log portion of trees $\geq$ 8.95 inches d.b.h.
US = Upper stem portion of trees $\geq$ 8.95 inches d.b.h.
AL = All live trees $\geq$ 0.95 inches d.b.h.

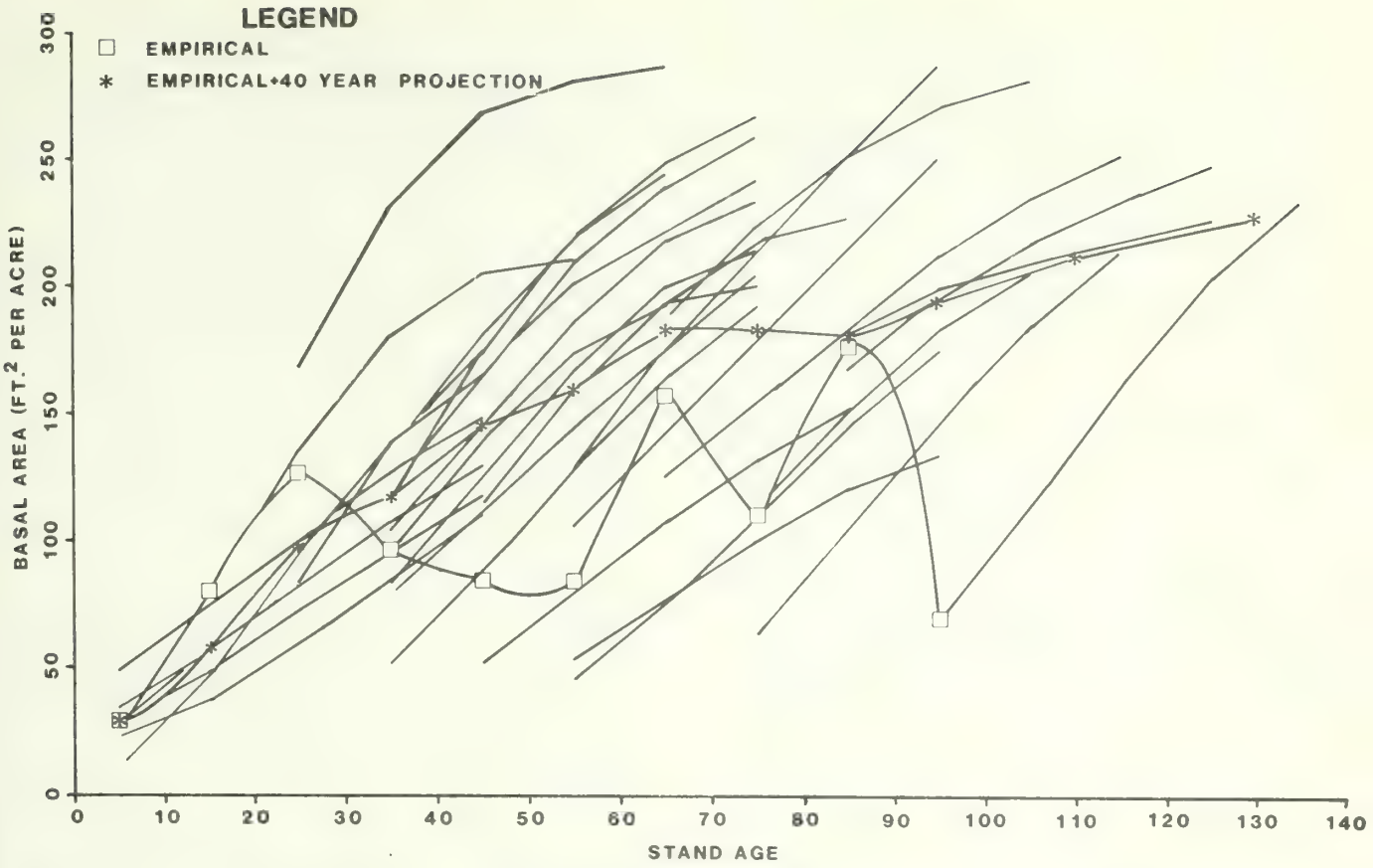


Figure 2.—*Basal area over age for* white and red pine (site index 61 +) *type by averaging option: empirical yield data; empirical yield data plus 40-year projections. Fine lines represent projections of a systematic sample of plots. Heavy (smoothed) lines are based on graphics package algorithm and included for illustration only. Based on 37 plots.*

growth data, there is validation information in the data. The growth model (STEMS) has been widely tested and is known to be adequate for short periods (Leary and Hahn 1979, Smith 1982). Also, graphs like figure 2 were evident for all but the red and white pine cover types. As in figure 1, the approximately parallel pattern of STEMS predictions around the empirical yield data curve suggests validity for both as descriptions of growth-over-age patterns. Until surveys are expanded or growth models are refined, this methodology does suggest a way to meet harvest scheduling analysis needs. It is offered here not as the ultimate approach, but as an operational strategy that we hope will be refined later.

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IMPACTS OF WOOD ENERGY USE ON TIMBER SUPPLY IN NORTHEASTERN MINNESOTA

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Forests in northeastern Minnesota have the biological potential to supply significantly more wood than currently is being consumed by existing forest industry. One often-suggested proposal is to utilize this timber supply surplus for energy production. This use might complement forest industry in both the short and long run. A short-run benefit would be the opportunity to recover the desirable species contained in the many mixed-species stands that wouldn't be harvested without an energy market. Although the proportion of desirable species in these stands is relatively low, the total volume of desirable species is large because these stands cover so many acres. A long-run benefit would be the increased future forest productivity due to harvesting now. Many older, slower growing stands need to be harvested now to achieve their productive potentials, and so-called "off-site" stands can be converted to more desirable species.

THE PROBLEM

A major concern about wood energy use is the negative impact it might have on existing forest industries. Undoubtedly, more stands might become marketable with a larger wood energy market, but how much wood suitable for existing industry would actually be burned? Obviously some of this material would be utilized simply because it is closer to a wood energy market or because it is too expensive to sort out during harvesting operations.

Northeastern Minnesota has an enormous biological supply of woody biomass (Raile and Jakes 1981), but the biological supply is quite different from the economic supply for specific forest industries. By definition, economic supply is a schedule that shows the quantity *producers are willing to sell at each price during a specified time period. Economic supply is a difficult concept for specific forest products, such as wood energy, for at least four reasons. First, many forest resources can be supplied to any one of several product markets, thus making the economic supplies of many forest products interrelated. Second, the supplies of not-so-similar forest products can also be interrelated because they occur as joint products in individual stands. Third, because considerable time is required to grow trees and because they can be harvested at different ages, the current economic supply and future economic supplies are interrelated; future economic supplies depend on actual harvest levels during prior periods. Fourth, the wood produced within a region is supplied by many different landowners, each with his own management objectives and strategies.*

Predicting the economic supply of wood energy or any other specific forest product is thus a difficult, if not impossible, task. Yet, it is important to better understand the value of increased wood energy use and how such increased use might affect timber supplies for other forest products.

OBJECTIVES

The objective of this study was to examine the economic timber supply situation in northeastern Minnesota to gain a better understanding of the opportunities for increased wood energy production. The objective was not to predict future wood energy consumption, but rather to try to examine the future opportunities that might be possible over a range of plausible future conditions. Specific objectives were to:

1. Determine least cost management schedules for producing plausible future timber product outputs.
2. For each least cost management schedule, identify the marginal production costs for each product and

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how they change as the wood energy production level changes.

3. For each least cost management schedule, estimate the net present worth (NPW) of the schedule under several wood energy price assumptions and identify how NPW would change as the wood energy production level changes.

4. Identify how wood energy production can best be incorporated into the joint timber production process.

METHODS

Energy models are typically not good forecasting devices. As discussed by Samouilidis (1980) "There is ample evidence, both theoretical and empirical to support this claim." The primary use of energy models is in gaining a better understanding of how systems operate. The system in this case is the timber production system in northeastern Minnesota. A relatively small region is considered because biomass energy must be considered on the basis of a specific market area (Silversides 1982). High transport costs and varying local wood markets force this perspective.

Several previous studies have looked at wood energy supply potential for specific areas of the Lake States. Raile and Jakes (1981) reported total green ton biomass estimates for northern Minnesota from the most recent forest survey information. Aube (1980) evaluated the economic feasibility of supplying a wood-fueled power plant in northern Minnesota. Bradley *et al.* (1980) examined the wood energy supply potential for northern Wisconsin and Michigan. But none of these studies attempted to measure the impact of increased wood energy use on the supply costs for other wood users. Methods for measuring such impacts are not well defined. Greber and Wisdom (1985) examined the short-term impact of wood energy use on existing pulpwood and saw log markets in eastern Virginia using a simulation model. They were able to identify substantial short-run interactions between markets, both complementary and competitive. Long-term interactions were not considered.

Linear programming (LP), which has been the major technique used in energy modelling (Samouilidis 1980), is also a primary tool used in forest-wide timber management scheduling. Significant information about timber supply costs can be gained from the dual variables associated with the optimal solution to an LP timber management scheduling model. Using a cost-minimization approach, the dual variable associated with each forest output level constraint represents the marginal cost of production for that output. By comparing the dual variables (marginal costs) for runs with different output levels over time, much can be learned about the impacts of wood energy output levels on the supply costs of other forest products. Model size is the greatest limiting factor in performing analyses of this type (Johnson and Scheurman 1977, Jameson *et al.* 1982); current LP timber management scheduling models were considered inadequate, because they could not recognize enough of the stand detail that is so important for wood energy considerations.

Instead, a scheduling method developed by Hoganson and Rose (1984) was used for this study. Their method was applied to a harvest scheduling linear program to minimize the cost of producing specified forest output levels. This method uses basic concepts of dynamic programming and timber production economics and is based on the dual interpretation of the problem. The dual variables associated with the forest output level constraints are the key dual variables in the solution process. If their values can be determined, then the problem can be decomposed and solved in parts. And because of this decomposition and solution in parts, significantly more stand detail can be included in this model.

The following steps comprise the method: (1) the key dual variables are estimated *a priori*, (2) these estimates are used to solve for the remaining variables, (3) the harvest schedule implied by these estimates is compared to the desired harvest schedule to determine the accuracy of the *a priori* estimates, and (4) if the errors in the estimates are significant, the implied schedule results are used to re-estimate the key dual variables and the process is repeated. If the implied schedule is close to the desired schedule, the key dual variable estimates must be close enough. The economic interpretation of the key dual variables and some simple concepts of timber production economics are important aspects of the re-estimation process used in step (4).

THE DATA

Data requirements were enormous. The study considered all forest lands in the seven northeastern Minnesota counties of Aitkin, Carlton, Cook, Itasca, Koochiching, Lake, and St. Louis, for a total of approximately 7.3 million acres. Ten 10-year planning periods were considered, with the first beginning in 1976, the year of the most recent forest survey.

The stand classification scheme, which allowed for over 6,000 initial stand types to be recognized in the model, was based on site type, current species mix, stand age, stocking level, distance to the nearest wood energy market, and distance to the nearest existing roundwood market. Twelve site types were recognized. Site types were defined by both the site productivity (site index) and the species mix that would result naturally after a clearcut. Each site type was divided into

classes based on species mix of the initial stand, with as many as 10 classes recognized per site type. Numerous species mixes were possible, thus a fair amount of aggregation was needed. During the aggregation process consideration was given to both the silvicultural characteristics and economic values of the species involved. Site by species-mix types were subdivided into 10-year age classes and two relative stocking levels (high or low). The final levels of classification were two distance-to-market identifiers, one representing the distance to a wood energy market and the other representing the distance to an existing roundwood market. Cities with a population of at least 2,000 were considered as energy markets. For both distance identifiers, the classes were three relative measures: close, medium, and far.

Twelve forest products were recognized by considering all combinations of four species groups—valuable softwoods, other softwoods, aspen, and other hardwoods—and three product size classes—saw logs, pulpwood, and other woody biomass. Output (production) levels for three forest product groups—softwoods, aspen, and wood energy—were used to define scenarios. All of the 12 forest product types were considered as possible wood energy sources. For example, other softwood pulpwood could be used to help meet either the softwood output level or the wood energy output level. Within each forest product type group, value differences were recognized among specific product types. For example, valuable softwood saw logs were assumed to be worth $40 more per thousand board feet than other softwood saw logs. Value differences were based on differences reflected in recent Minnesota forest product price reports.

U.S. Forest Service permanent survey plots were used as the basis for describing the initial conditions of the forest (Jakes 1980). Plot locations were linked with a classified grid describing the relative location indices. Information on the location and demand of existing markets was obtained from a number of sources, including Blyth *et al.* (1979), Blyth and Smith (1983), and Milton and Krantz (1982).

Growth and yield data requirements were enormous. Considerable growth and yield information is available, but very little specific attention has been given to the differences in species mixtures that occur within a given major species type. For example, all stands with aspen as the major species are usually lumped together, with little attention given to how aspen stands vary in terms of other species present. Information is also lacking for making accurate long-term growth projections.

Growth and yield information was developed using a technique developed by Ek *et al.* (1984) that combined recent survey data with projections from the STEMS growth projection model (Belcher *et al.* 1982) to develop empirical yield tables (Husch *et al.* 1972). Computer software was developed to automate the process of using the empirical yield tables and harvest cost information to formulate possible management alternatives for individual stand types. Prescriptions included the timing and amount of all costs and yields. The prescriptions were primarily clearcuts that varied significantly as to the time of harvest and the type of harvest system applied. Traditional roundwood-only systems, full-tree chipping systems, and chip-and-sort systems were all considered. Harvest cost estimates were based on harvest cost and production data described by Bowyer and Hazenstab (1984). Thinning alternatives were considered for red pine sites.

Dynamic programming was utilized to link first-rotation management alternatives with regeneration alternatives. The latter included natural as well as artificial options, such as site conversion to valuable softwood species. A "no harvest" option assumed that the stand followed natural succession toward either a climax hardwood or softwood type. The natural regeneration options were based on the same growth and yield information developed for the initial rotations. Alternatives for red pine plantations developed by Lundgren (1981) and modified by Lothner and Bradley (1984) represented the valuable softwood conversion option.

Wood consumption levels are difficult if not impossible to predict for periods far into the future. Instead of attempting to forecast specific consumption levels for each product group, six plausible scenarios in future output levels were considered (table 1). Each scenario is defined by a set of desired output levels over time for the aspen and softwood product groups, and a general assumption about the future role of wood energy: wood energy use will continue indefinitely at a constant level or remain constant for the next 30 years and then drop to 400,000 dry tons per year, a level close to the existing consumption level. Both a constant output trend and a rising output trend were considered for aspen and softwoods. Under the rising softwood trend, the increase is linear such that the output in period 9 is double the output in period 1. For all scenarios, the aspen output level increases between period 1 and period 2 to reflect the recent growth in the waferboard industry. For the rising aspen trend, output does not increase again until period 5, because preliminary results indicate that aspen is currently close to its maximum sustainable level. The specific desirable output levels considered for the aspen and softwood product groups are shown in table 2 in the Appendix.

Table 1.--Description of the six scenarios

Scenario	Description
1	Aspen and softwood outputs constant over time and wood energy use continuing indefinitely.
2	Aspen output constant over time, softwood output increasing over time, and wood energy use continuing indefinitely.
3	Aspen and softwood outputs constant over time and wood energy use primarily a 30-year opportunity.
4	Aspen output constant over time, softwood output increasing over time, and wood energy use primarily a 30-year opportunity.
5	Aspen output increasing after 40 years, softwood output constant over time, and wood energy use primarily a 30-year opportunity.
6	Aspen output increasing after 40 years, softwood output increasing over time, and wood energy use primarily a 30-year opportunity.

RESULTS

Several runs of the timber management scheduling model were performed for each of the six scenarios, for a total of 34 runs. The final marginal cost estimates for each run are shown in the Appendix. In the pages that follow, the major relationships identified will be described, the schedules developed for one scenario will be summarized briefly, and implications of the scheduling results for selecting a wood energy output level will be considered.

Supply Cost Interactions

Graphs of marginal production costs plotted against time are good indicators of the general timber supply situation. For a perfectly regulated, one-product forest in which output levels remain constant over time, the plot of marginal production cost against time (using corresponding period dollars) would be horizontal. If the age distribution of the forest were imbalanced then a cyclical line would be expected. Market location, multiple product interactions, and changing output levels are just some of the factors that can change the marginal production costs of specific timber products over time. In this section the focus will be on the impact of alternative wood energy output levels on the marginal production costs of three timber product groups recognized in the model.

Aspen marginal costs plotted against time for scenario 1 indicate both a complementary (fig. 1) and competitive (fig. 2) relationship between wood energy use and aspen production. Aspen marginal production costs decreased as wood energy production level increased from 1 to 10 million dry tons per decade, and then increased as the wood energy production level increased from 10 to 30 million dry tons per decade. Between the 6 and 12 million levels, changes were insignificant, but increasing the wood energy output from 20 to 30 million dry tons per decade greatly increased aspen marginal costs.

All of the aspen marginal cost curves for scenario 1 peak in year 2010 (figs. 1 and 2). These peaks reflect the general aspen "shortage" that has been projected for the area because of imbalances in aspen age distribution. Forty years is the minimum rotation age assumed for aspen in the model; aspen marginal costs drop by 2020 because benefits from regeneration work undertaken in the first period are realized.

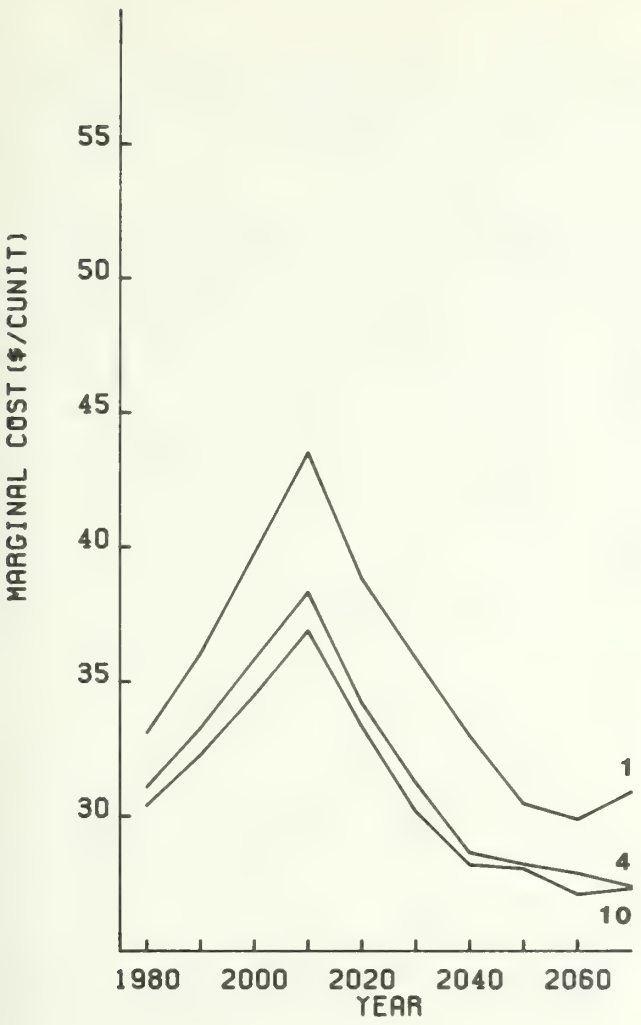


Figure 1.—*Aspen marginal cost estimates for low wood energy levels for scenario 1: aspen output constant, softwood output constant, and wood energy use continuing indefinitely. (Curve labels indicate the wood energy output level in millions of dry tons per decade.)*

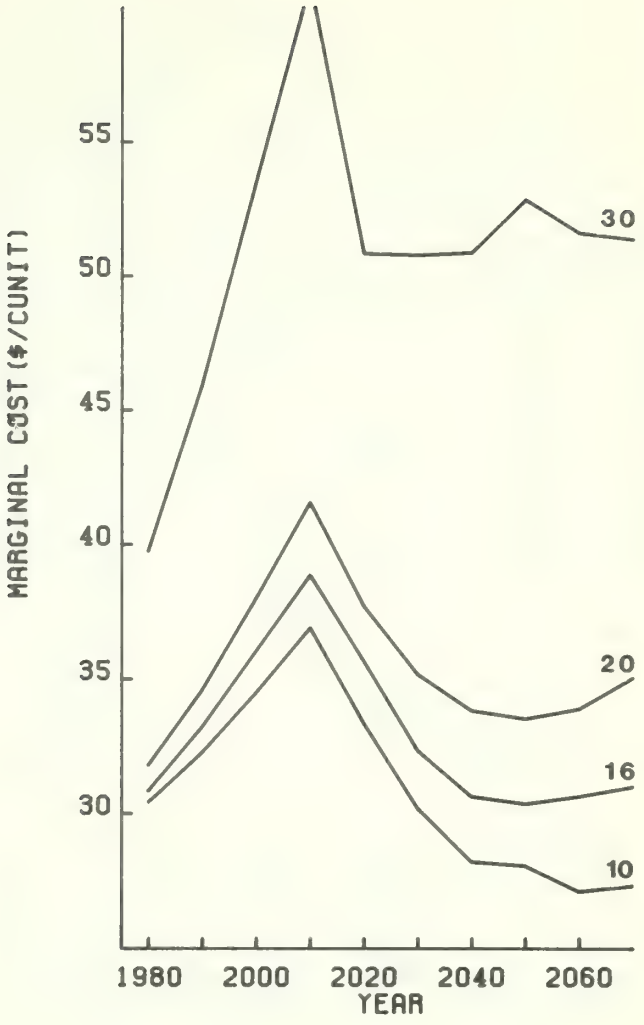


Figure 2.—*Aspen marginal cost estimates for high wood energy levels for scenario 1: aspen output constant, softwood output constant, and wood energy use continuing indefinitely. (Curve labels indicate the wood energy output level in millions of dry tons per decade.)*

Softwood marginal cost estimates are not sensitive to the wood energy output levels examined for scenario 1 (fig. 3) until 30 million dry tons per decade. One interesting observation is the correlation between softwood marginal costs and aspen marginal costs. Marginal costs for softwoods increase rapidly after the 2010 decade—the decade in which aspen marginal costs begin to decrease. This increase can be explained by the fact that by the 2020 decade, aspen stands regenerated in the first period will be available for harvest; then, because the aspen market will no longer depend as much on mixed stands for harvest, the softwood market will have to absorb more of the costs of harvesting mixed stands or rely more heavily on the purer softwood stand types located farther from the market.

As expected, higher wood energy output levels for scenario 1 resulted in higher wood energy marginal costs (fig. 4). For all but the 30 million dry tons per decade level, wood energy marginal costs increase only slightly over time. Intuitively, one might expect a greater increase over time because of current species composition and imbalances in age distribution—that is, the forests of northeastern Minnesota now have a higher percentage of older trees and less desirable (wood energy) species than they will have in the second and subsequent rotations. A possible explanation for only a slight increase is that future rotations will contain more fully-stocked stands and thus more wood will be available in general. Another factor is that minimum rotation ages for strictly wood energy harvest were set quite high, thus making the current age distribution not as "imbalanced" in terms of wood energy use. Also, with any increase in wood energy marginal costs, the full-tree chipping operations are selected for more sites

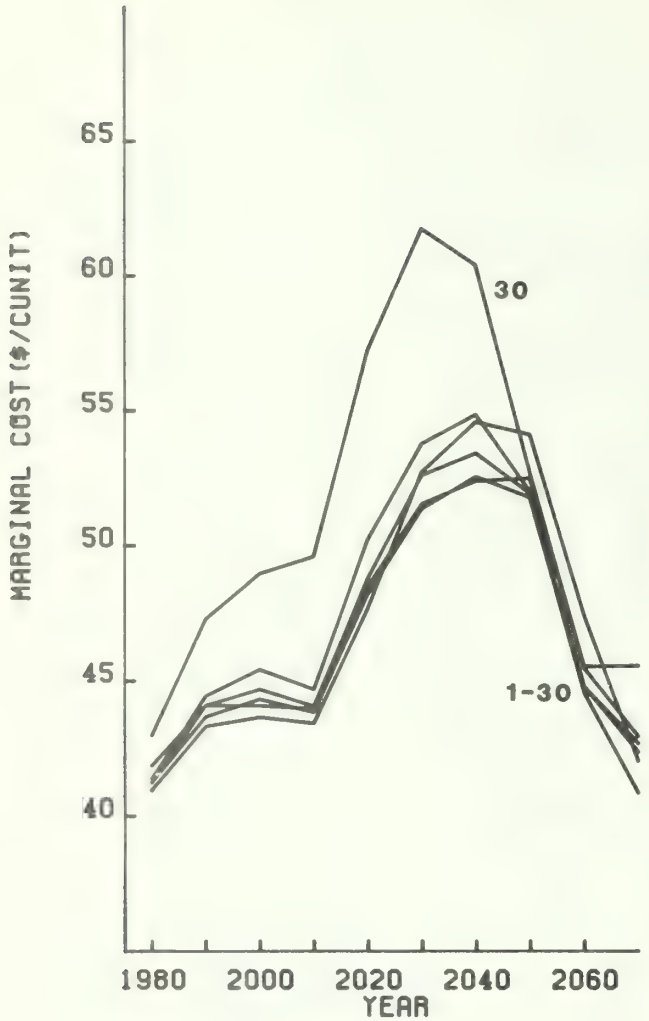


Figure 3.—*Softwood marginal cost estimates for different wood energy levels for scenario 1: aspen output constant, softwood output constant, and wood energy use continuing indefinitely. (Curve labels indicate the wood energy output level in millions of dry tons per decade.)*

and thus fewer stands are needed to meet the wood energy output levels.

Also of interest are the low wood energy marginal costs for low wood energy output levels (fig. 4). These low costs indicate a complementary relationship between wood energy and other forest products. Wood energy marginal cost estimates include both the direct per-unit cost of harvesting and transporting wood energy at the margin and the indirect impacts of that marginal unit on the production costs for other forest products. Based on the harvest and transport costs used in the study and assuming wood energy to be the only forest product, wood could be harvested and transported for about $13 per dry ton from stands located close to an energy market with low per dry ton harvest costs. But for low wood energy production levels (fig. 4) the wood energy marginal costs are lower than the

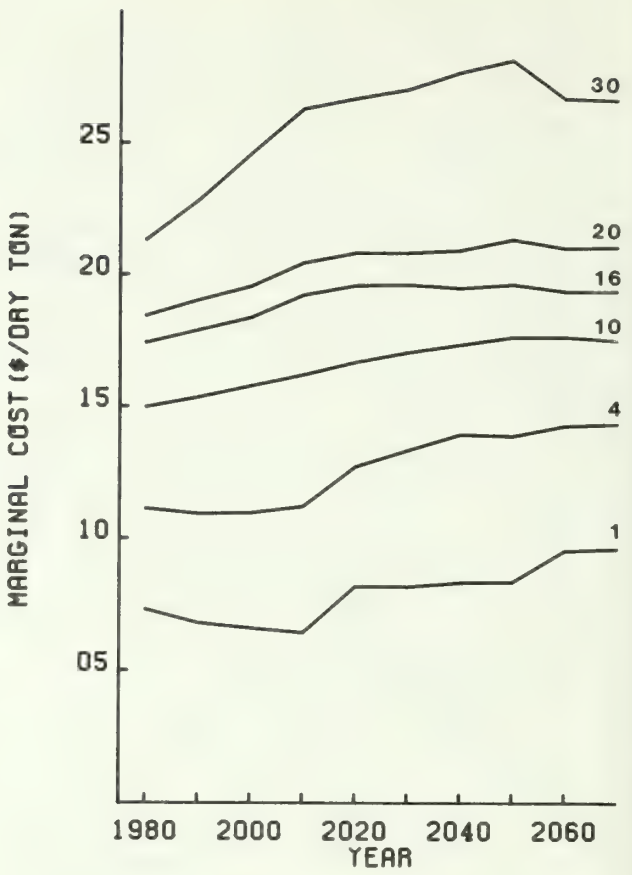


Figure 4.—*Wood energy marginal cost estimates for different wood energy levels for scenario 1: aspen output constant, softwood output constant, and wood energy use continuing indefinitely. (Curve labels indicate the wood energy output level in millions of dry tons per decade.)*

direct costs of harvesting and transporting even these low-cost stands; therefore, the indirect costs of wood energy on other products must be negative (complementary).

The results described to this point have all dealt with scenario 1: fixed and constant aspen and softwood output levels over time, and wood energy levels maintained throughout the planning horizon. As expected, softwood marginal costs are higher for scenarios that assume softwood outputs will increase over time, and aspen marginal costs are higher for scenarios that assume aspen outputs will increase over time. For all six scenarios, trends in the softwood marginal costs over time were similar to those for scenario 1 (fig. 3); and for wood energy levels up to 20 million dry tons per decade, softwood marginal costs are not sensitive to the wood energy level. Softwood marginal cost estimates do not increase even when the wood energy level is set at 30 million dry tons per decade for scenarios 3, 4, 5, and 6, the scenarios in which wood energy opportunities are considered as primarily short-term (30-year). In general, the relative insensitivity of softwood marginal

costs to wood energy output level is likely due to the fact that softwood harvests, even under the rising softwood output assumption, are well below potential levels.

Marginal cost estimates for wood energy depend on the assumption made about the future role of wood energy use. Figure 5 compares the wood energy marginal cost estimates for all six scenarios when wood energy level is set at 20 million dry tons per decade. For this level, as well as for other wood energy levels, the marginal cost curves fall into two groups: curves for scenarios that assume wood energy to be primarily a short-term (30-year) opportunity, and curves for scenarios that assume wood energy to be a long-term (100-year or more) opportunity. It is not surprising that marginal costs decrease for the 30-year scenarios soon after the wood energy output level drops. What is interesting is the similarity of the marginal costs within each group.

Marginal cost estimates for the aspen product group differ the most between scenarios. However, aspen marginal costs for scenario 2 are quite similar to those for scenario 1 (figs. 1 and 2). Aspen marginal costs for scenario 2 differ only in that they are lower for periods prior to period 5 (approximately $1 lower) if energy output levels are not above 10 million dry tons per decade, and they are higher for periods beyond period 5 (approximately $3 higher) if the energy output level is set at or above 20 million dry tons per decade. These slight differences can be explained by the differences in assumptions between scenarios 1 and 2: scenario 2 has the softwood output level rising over time while in scenario 1 it remains constant. If wood energy consumption is low, then increased softwood consumption could complement aspen production in the short run in a way similar to the complementary impact of increased wood energy consumption on aspen for lower wood energy levels. At higher wood energy levels, the short-run complementary impact on aspen from rising softwood consumption would not be as great because much of the complementary impact could be achieved through the harvesting for wood energy. Rising softwood consumption could obviously have a long-run competitive effect on aspen because of the rising need for land to grow (regenerate) softwoods; the comparison between scenario 1 and 2 shows the effect would be greater when timber consumption in general is higher.

Aspen marginal cost estimates for scenario 3 are similar to those for scenario 4 (fig. 6). The general shapes of the curves are similar to the shapes found in the first two scenarios. The major differences are that the marginal costs are not quite as sensitive to the wood energy output level and that marginal costs are not as high for high wood energy levels. These types of results

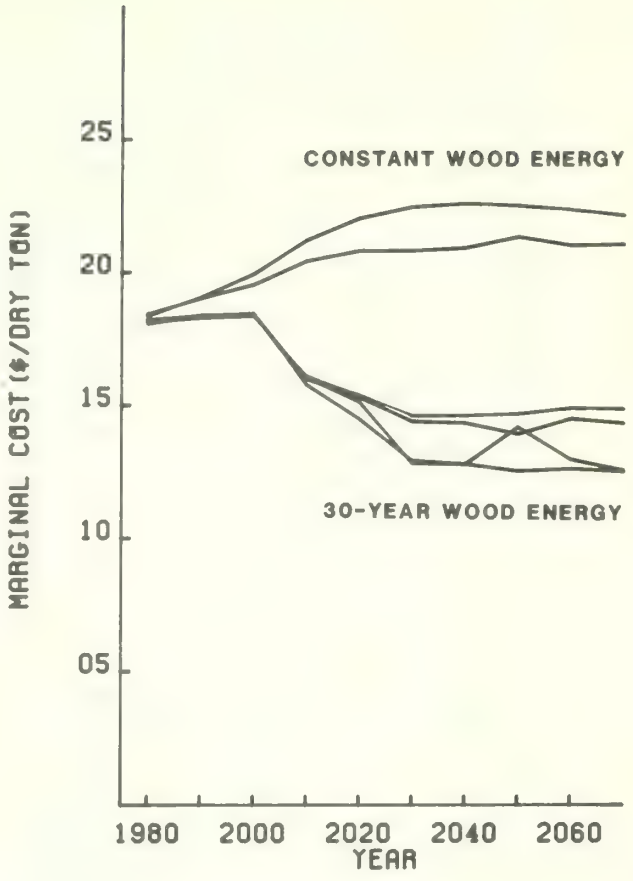


Figure 5.—*Wood energy marginal cost estimates for each of the six scenarios when wood energy output is 20 million dry tons per decade. (Each curve represents a different scenario)*

would be expected from these two scenarios because they consider wood energy use as primarily a short-term opportunity.

Scenarios 5 and 6 have similar aspen marginal cost estimates. For these scenarios, aspen output levels are rising over time. Figure 7, which portrays the aspen marginal cost estimates for scenario 5, shows a definite advantage in the long run for higher wood energy output levels; higher wood energy output levels have lower aspen marginal costs in all periods beyond 2010. This complementary impact of wood energy use on aspen must be due to the fact that many stands will regenerate naturally after harvest to a stand with an even greater aspen component. The complementary impact is greater for scenarios 5 and 6 because these are the scenarios in which future aspen consumption is greatest. Another interesting point from figure 7 is that even with increased wood energy harvesting in the short run, aspen marginal costs in the short run do not increase significantly until the wood energy output level rises above the 30 million dry tons per decade level.

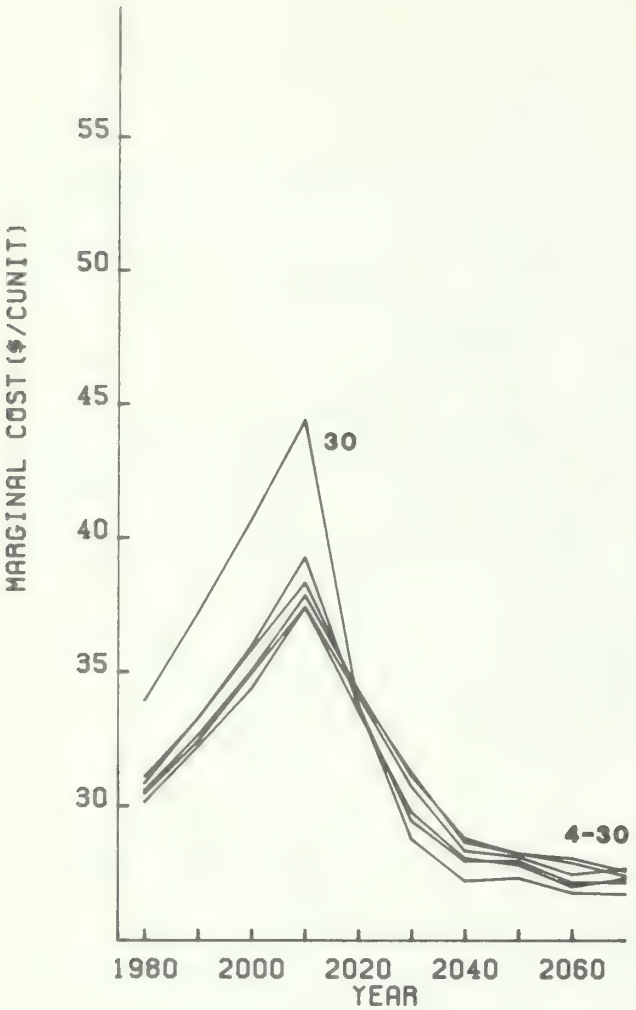


Figure 6.—*Aspen marginal cost estimates for different wood energy levels for scenario 3: aspen output constant, softwood output constant, and wood energy use primarily a 30-year opportunity. (Curve labels indicate the wood energy output level in millions of dry tons per decade per year.)*

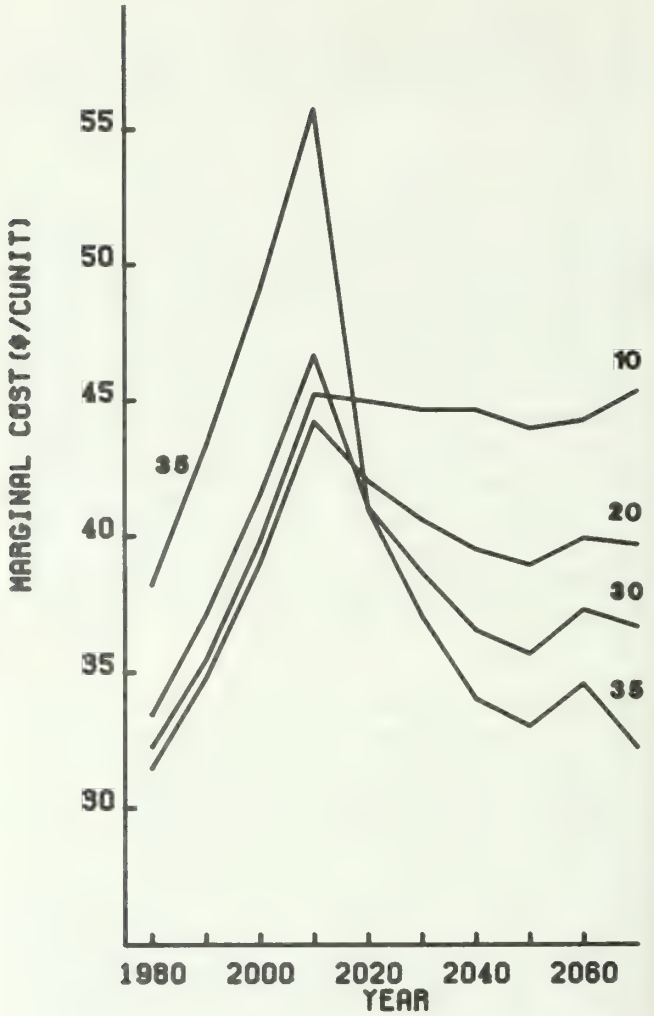


Figure 7.—*Aspen marginal cost estimates for different wood energy levels for scenario 5: aspen output increasing after 40 years, softwood output constant, and wood energy primarily a 30-year opportunity. (Curve labels indicate the wood energy output level in millions of dry tons per decade per year.)*

Least Cost Management Schedules

A major concern with wood energy use is the type of wood that would actually be burned. Obviously the surplus dense hardwoods are well suited for energy production, but stand locations or harvest cost considerations might make it advantageous to burn other species. For scenario 1 almost all of the wood energy at the lower levels of wood energy use is supplied from the other-hardwood category over the entire planning horizon (fig. 8). At higher levels of use more wood energy is supplied from the aspen and softwood categories. A significant portion of this wood, however, is likely to be tops and limbs that would be chipped in chip and sort operations. Unfortunately, the model was not structured to identify the quantities of aspen or softwood roundwood that would be burned.

Looking at just period 1 schedules gives us an idea of what should be done today. The scenario 1 summary for period 1 (fig. 9) shows even higher percentages of wood energy coming from hardwoods than the scenario 1 summary for the entire planning horizon. Even at high levels of wood energy consumption only small percentages are supplied from the aspen and softwood categories. These statistics are somewhat misleading, however, in that one would not expect any evidence, like that shown earlier, of a competitive impact between wood energy use and other timber uses if significant volumes of other products are not burned. Significant volumes are burned at higher wood energy levels because even though the actual percentages are low, the wood energy levels are high enough to make even small percentages significant (fig. 10).

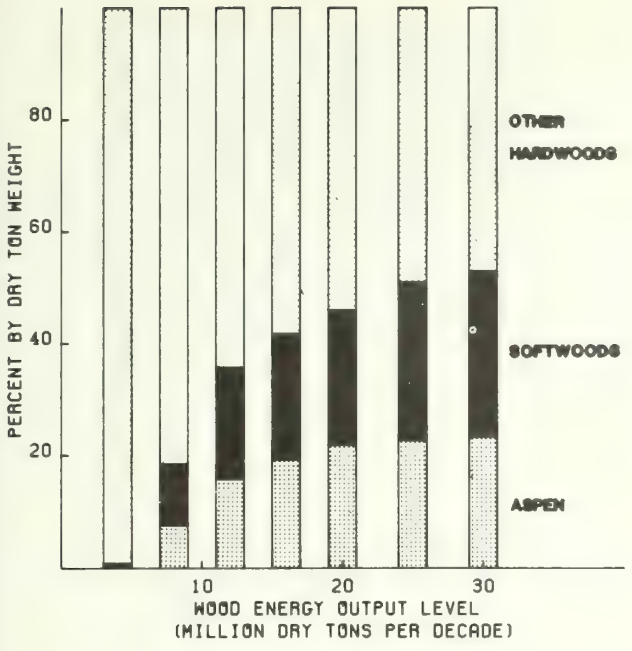


Figure 8.—*Species group breakdown of wood energy consumption for the entire planning horizon as scheduled for different wood energy output levels for scenario 1.*

Another important factor is the form in which wood is harvested for energy use. In this study no value differential was assumed for the form in which wood energy is delivered to the user. Most residential users prefer roundwood, but the larger commercial users prefer chips. Based on the no value differential assumption

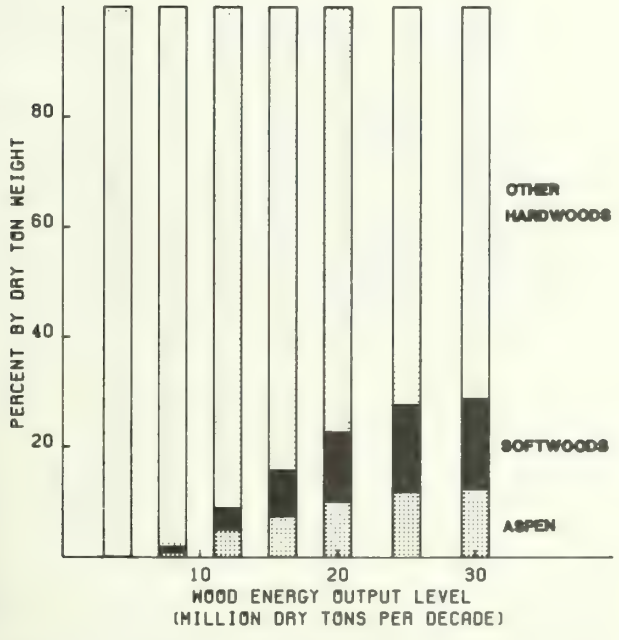


Figure 9.—*Species group breakdown of wood energy consumption for period 1 as scheduled for different wood energy output levels for scenario 1.*

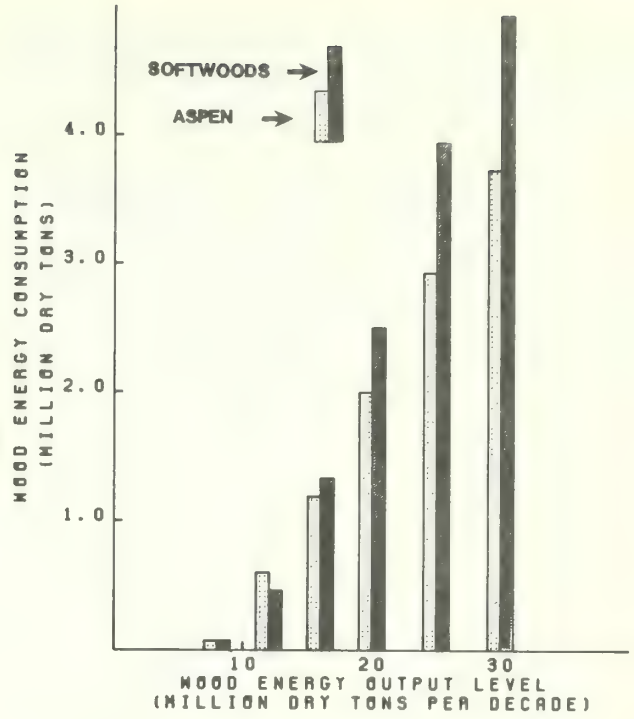


Figure 10.—*Aspen and softwood consumed as wood energy during period 1 as scheduled for different wood energy output levels for scenario 1.*

the form in which wood energy would be delivered is quite sensitive to the wood energy output level (fig. 11). At low output levels, traditional roundwood operations are favored as there is plenty of wood to meet all uses without concern about leaving burnable material in the

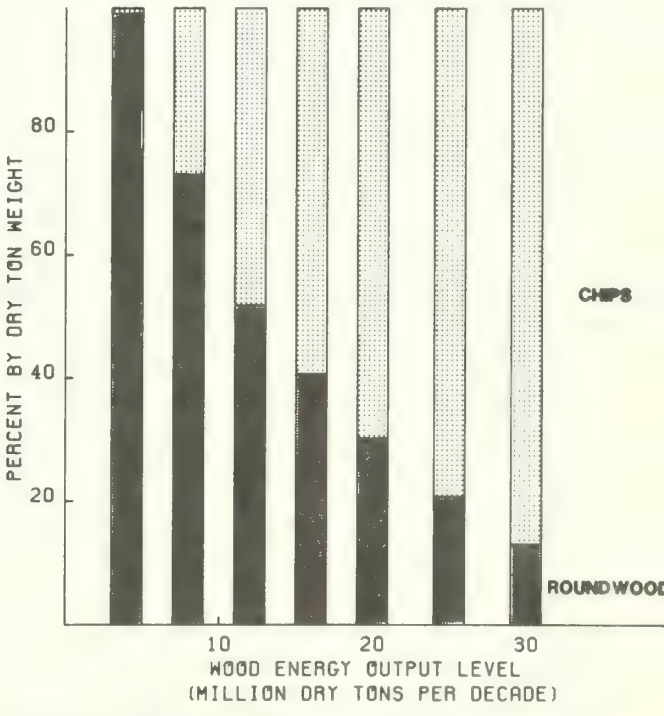


Figure 11.—*Method of harvest breakdown over all periods for wood energy consumption as scheduled for different wood energy output levels for scenario 1.*

woods. These results might be quite different, however, if a value differential were assumed between roundwood and chips.

Selecting a Wood Energy Consumption Level

The supply cost interactions examined earlier give an indication of the impacts of wood energy use on the supply costs for other forest products, but the optimum wood energy production level is not necessarily the level at which the net positive impact on other timber consumers is maximized. Identifying and quantifying impacts on other timber consumers is important only to the extent that this information can be helpful in developing policies to help allocate both the benefits and costs of a wood energy development program. From a strict production economics viewpoint, the optimal wood energy production level is still the level at which marginal revenue from wood energy equals marginal cost where both direct and indirect revenues and costs are recognized. If there are equity problems at this level, policies should be sought that can help redistribute impacts.

Identifying the production level where marginal cost equals marginal revenue is difficult, because both revenues and costs are hard to measure. Revenues generated from today's regeneration actions will not be received for many years; in the interim, timber prices can change significantly. Impacts of activities on nonmarket resources, such as wildlife, water, and recreation, are also difficult to measure. However, increased timber use in northeastern Minnesota would probably not be detrimental to nonmarket forest resources unless the increase were quite substantial. Significant costs the analysis did not recognize include sales administration and road construction. Obviously, roads serve many purposes, and allocating all road costs to timber production does not seem appropriate. Road costs are also difficult to incorporate into a timber scheduling model because a single road often serves many stands, thus making it difficult to assign road costs to a specific alternative for a specific stand.

From a regional perspective, the impact of forestry activities on the economy can be enormous. Undoubtedly, increased harvest means increased jobs, and northeastern Minnesota is currently suffering high unemployment. Viewed in this light, it would seem that the more wood energy use the better. But future wood industry expansion opportunities could be affected by the amount of wood allocated to wood energy today. Wood-using industries based on new technologies could plausibly materialize, producing a much greater economic impact on the region than wood energy. Developing strategies for wood energy development is thus an issue that needs attention from the political arena.

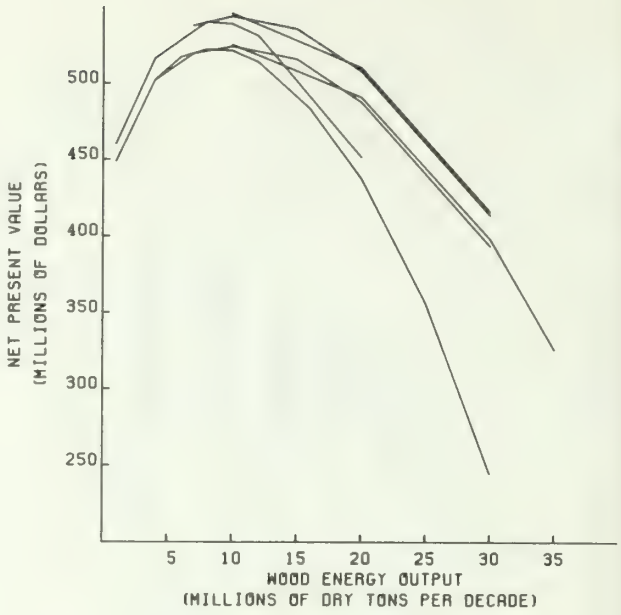


Figure 12.—*Net present worth estimates for the schedules developed for each scenario assuming that the wood energy, as produced, is worth $15 per dry ton. (Each curve represents a different scenario.)*

As part of the analysis, the NPW of each schedule produced was estimated once for each of two different sets of assumptions describing future product prices. These sets all assumed constant real prices over time and differed only in the assumptions made concerning the price of wood energy. The two wood energy prices considered were $15 and $25 per dry ton. The absolute magnitude of each NPW estimate is extremely sensitive to the prices assumed. Of real interest is a comparison of the NPW's for alternative levels of wood energy production for each set of price assumptions.

Figure 12 compares the NPW estimates for the assumption that wood energy is worth $15 per dry ton. Each curve represents one of the six scenarios considered. For each scenario and this wood energy price assumption, NPW is maximized at approximately the 12 million dry tons per decade level. As discussed earlier, this wood energy production level could complement production of other timber products.

Figure 13 compares the NPW estimates for the assumption that wood energy is worth $25 per dry ton. As in figure 12, each curve represents one of the six scenarios. For each scenario and this wood energy price assumption, NPW is maximized at the highest wood energy consumption level examined. This suggests there is a large opportunity cost of not better utilizing the timber resource. For example, the NPW for the 30 million dry tons per decade level exceeds the NPW for the 10 million dry tons per decade level by approximately $300 million. The continuously increasing NPW

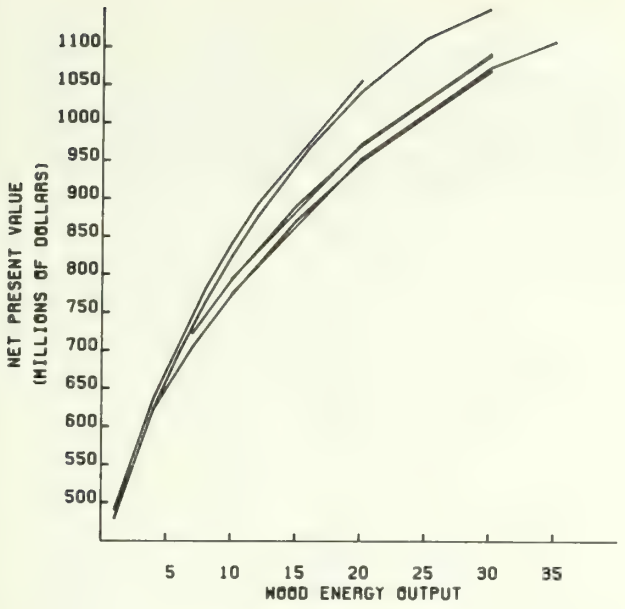


Figure 13.—*Net present worth estimates for the schedules developed for each scenario assuming that the wood energy, as produced, is worth $25 per dry ton. (Each curve represents a different scenario)*

values with higher wood energy levels suggest that even higher wood energy levels be considered. However, for the silvicultural systems considered, consumption levels could not be increased significantly without reaching the maximum biological limit.

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Table 2.--Output levels considered for the aspen product group and the softwood product group

(In thousands of cunits per decade)

Period midpoint year	Aspen		Softwood	
	Constant output trend	Increasing output trend	Constant output trend	Increasing output trend
1980	5,500	5,500	4,000	4,000
1990	7,000	7,000	4,000	4,500
2000	7,000	7,000	4,000	4,500
2010	7,000	7,000	4,000	5,500
2020	7,000	7,500	4,000	6,000
2030	7,000	8,000	4,000	6,500
2040	7,000	8,500	4,000	7,000
2050	7,000	9,000	4,000	7,500
2060	7,000	9,000	4,000	7,500
2070	7,000	9,000	4,000	8,000

Table 3.--Marginal costs of production for alternative wood energy production levels for scenario 1: aspen output constant, softwood output constant, and wood energy use continuing indefinitely

Period midpoint year	Ten-year wood energy production level (Millions of dry tons)									
	1	4	6	8	10	12	16	20	25	30
	ASPEN (Dollars per cunit)									
1980	33.11	31.11	30.58	30.22	30.41	30.44	30.84	31.79	34.56	39.74
1990	36.06	33.28	32.54	32.09	32.29	32.41	33.22	34.59	38.62	45.93
2000	39.77	35.83	34.69	34.11	34.49	34.59	36.04	38.00	43.95	53.49
2010	43.51	38.32	36.81	36.28	36.89	37.14	38.86	41.56	49.36	60.92
2020	38.81	34.19	33.15	33.02	33.33	33.95	35.63	37.68	43.71	50.82
2030	35.87	31.25	30.08	29.89	30.18	30.61	32.33	35.16	42.55	50.77
2040	32.99	28.65	28.27	28.32	28.19	28.41	30.62	33.80	41.57	50.86
2050	30.47	28.22	27.97	28.21	28.05	28.27	30.35	33.51	40.66	52.84
2060	29.88	27.88	27.09	27.17	27.10	27.69	30.64	33.88	40.78	51.59
2070	30.91	27.40	27.29	27.29	27.32	27.64	31.00	35.04	41.02	51.35
	SOFTWOODS (Dollars per cunit)									
1980	40.96	41.86	41.25	41.37	41.25	41.05	41.24	41.38	41.69	42.98
1990	43.32	44.09	43.67	43.52	43.68	43.61	44.09	44.44	45.05	47.28
2000	43.66	44.08	44.06	44.04	44.32	44.18	44.69	45.41	46.19	48.96
2010	43.43	43.96	43.74	43.75	43.83	43.40	44.05	44.68	45.65	49.60
2020	47.68	48.47	47.85	48.22	48.21	48.02	48.79	50.22	50.43	57.22
2030	52.73	51.55	51.19	51.56	51.36	51.25	52.60	53.76	54.72	61.73
2040	54.57	52.39	52.20	52.54	52.54	52.86	53.42	54.84	55.29	60.37
2050	54.09	52.50	52.11	51.18	51.76	51.90	51.91	51.97	53.43	52.66
2060	47.39	45.44	45.04	44.31	44.55	45.07	44.77	44.77	46.12	45.52
2070	42.03	42.94	41.90	41.81	40.84	40.70	42.35	42.67	45.99	45.54
	WOOD ENERGY (Dollars per dry ton)									
1980	7.30	11.12	13.13	14.04	14.98	15.86	17.41	18.43	19.68	21.32
1990	6.78	10.92	13.02	14.20	15.35	16.42	17.90	19.03	20.61	22.83
2000	6.59	10.97	13.27	14.52	15.78	16.95	18.38	19.56	21.70	24.59
2010	6.42	11.22	14.04	15.20	16.21	17.48	19.24	20.46	22.94	26.31
2020	8.19	12.73	14.86	15.49	16.69	17.96	19.60	20.84	23.39	26.70
2030	8.18	13.35	15.10	15.90	17.07	18.20	19.64	20.85	23.60	27.06
2040	8.34	13.95	15.52	16.41	17.36	18.16	19.51	20.95	23.76	27.72
2050	8.36	13.90	15.82	16.71	17.66	18.34	19.66	21.38	24.06	28.18
2060	9.56	14.29	15.74	16.71	17.67	18.22	19.40	21.05	23.20	26.72
2070	9.63	14.37	15.97	16.89	17.54	18.21	19.41	21.09	23.31	26.67

Table 4.--Marginal costs of production for alternative wood energy production levels for scenario 2: aspen output constant, softwood output increasing, and wood energy use continuing indefinitely

Period midpoint year	Ten-year wood energy production level (Millions of dry tons)					
	1	4	8	10	12	20
	ASPEN (Dollars per cunit)					
1980	32.26	30.08	29.46	29.04	29.23	32.10
1990	34.69	31.76	30.85	30.25	30.50	35.11
2000	37.53	33.38	32.25	31.63	32.05	39.06
2010	40.60	34.99	33.96	33.22	33.89	43.15
2020	36.45	32.28	31.76	31.39	32.10	40.86
2030	33.84	29.29	29.08	28.85	29.19	39.20
2040	31.52	28.08	28.17	27.66	28.17	37.86
2050	29.38	28.24	27.97	27.89	28.60	37.61
2060	29.22	27.47	27.33	26.84	27.88	36.64
2070	29.64	28.05	27.52	27.17	28.55	38.50
	SOFTWOODS (Dollars per cunit)					
1980	43.24	43.47	43.04	43.15	43.20	43.47
1990	46.99	47.10	46.41	46.78	46.80	47.81
2000	48.71	48.52	47.98	48.65	48.38	49.77
2010	50.20	49.99	48.85	49.28	49.13	50.66
2020	55.50	54.07	52.59	53.08	53.13	55.28
2030	58.87	57.16	56.05	56.58	56.65	58.71
2040	59.70	57.80	56.76	57.37	57.57	59.56
2050	57.32	55.85	53.21	52.71	52.65	52.57
2060	50.04	48.88	46.74	46.18	46.05	46.20
2070	45.44	44.35	42.82	42.46	41.96	43.85
	WOOD ENERGY (Dollars per dry ton)					
1980	6.65	10.43	14.01	14.92	15.84	18.37
1990	6.35	10.38	14.15	15.37	16.44	19.07
2000	6.14	10.34	14.62	15.85	17.05	19.95
2010	6.17	10.66	15.30	16.33	17.65	21.24
2020	7.53	12.56	15.96	16.96	18.18	22.07
2030	7.92	13.45	16.45	17.45	18.52	22.50
2040	8.23	14.08	16.96	17.88	18.70	22.62
2050	8.35	14.63	17.12	17.87	18.73	22.54
2060	9.53	14.65	17.08	17.81	18.34	22.39
2070	9.62	14.63	17.13	17.80	18.22	22.18

Table 5.--Marginal costs of production for alternative wood energy production levels for scenario 3: aspen output constant, softwood output constant, and wood energy use primarily a 30-year opportunity

Period midpoint year	Ten-year wood energy production level (Millions of dry tons)					
	4	7	10	15	20	30
	ASPEN (Dollars per cunit)					
1980	31.11	30.59	30.47	30.15	30.86	33.93
1990	33.28	32.65	32.42	32.22	33.27	37.20
2000	35.83	35.05	34.93	34.38	35.97	40.68
2010	38.32	37.84	37.41	37.40	39.27	44.39
2020	34.19	34.30	34.11	33.52	33.74	33.77
2030	31.25	31.12	30.71	29.76	29.44	28.76
2040	28.65	28.79	28.32	28.05	27.95	27.21
2050	28.22	28.22	28.11	27.81	27.95	27.32
2060	27.88	28.05	27.45	27.00	27.15	26.76
2070	27.40	27.59	27.66	27.30	27.16	26.71
	SOFTWOODS (Dollars per cunit)					
1980	41.86	40.73	40.35	40.84	40.48	40.34
1990	44.09	42.90	42.42	43.36	42.89	43.03
2000	44.08	43.20	42.73	43.86	43.48	43.44
2010	43.96	42.86	42.58	43.34	43.26	43.65
2020	48.47	46.81	46.70	47.59	48.07	49.10
2030	51.55	51.14	51.16	50.98	51.74	52.31
2040	52.39	52.75	52.59	51.74	52.21	52.37
2050	52.50	51.86	51.64	51.40	50.44	49.30
2060	45.44	45.13	44.65	44.37	43.53	42.49
2070	42.94	40.61	39.69	41.15	41.02	40.80
	WOOD ENERGY (Dollars per dry ton)					
1980	11.12	13.63	14.80	16.72	18.21	20.03
1990	10.92	13.56	15.04	16.90	18.37	20.57
2000	10.97	13.53	15.11	16.94	18.46	20.90
2010	11.22	13.49	14.32	15.50	15.99	16.67
2020	12.73	13.83	14.55	15.08	15.31	15.62
2030	13.35	13.81	13.91	14.36	14.40	14.77
2040	13.95	13.37	13.42	14.08	14.34	14.64
2050	13.90	13.35	13.42	13.78	13.93	14.30
2060	14.29	13.58	13.68	14.30	14.51	14.50
2070	14.37	13.88	13.85	14.43	14.34	14.70

Table 6.--Marginal costs of production for alternative wood energy production levels for scenario 4: aspen output constant, softwood output increasing and wood energy use primarily a 30-year opportunity

Period midpoint year	Ten-year wood energy production level (Millions of dry tons)				
	7	10	15	20	30
	ASPEN (Dollars per cunit)				
1980	29.72	29.31	29.31	29.85	33.26
1990	31.27	30.65	30.81	31.75	36.15
2000	33.02	32.24	32.38	33.69	39.30
2010	35.05	34.21	34.84	36.46	42.41
2020	32.39	31.96	32.06	32.73	33.58
2030	29.25	28.79	28.94	28.92	29.16
2040	28.02	27.83	27.68	27.73	27.18
2050	28.15	27.88	27.75	27.90	27.66
2060	27.33	27.07	26.92	27.13	26.86
2070	27.78	27.53	27.35	27.12	26.53
	SOFTWOODS (Dollars per cunit)				
1980	42.99	42.73	42.85	42.68	43.56
1990	46.19	45.94	46.40	46.23	47.57
2000	47.38	47.44	47.78	47.47	48.95
2010	48.22	47.89	48.38	48.07	50.33
2020	52.26	51.87	51.88	51.56	53.66
2030	55.95	55.50	55.37	54.94	56.52
2040	56.60	56.27	55.56	54.86	54.49
2050	54.00	53.04	51.79	50.23	47.53
2060	47.38	46.37	45.77	44.40	42.18
2070	42.26	41.24	41.14	42.08	42.17
	WOOD ENERGY (Dollars per dry ton)				
1980	13.25	14.71	16.50	18.08	20.15
1990	13.14	14.95	16.92	18.36	20.80
2000	13.35	15.19	16.96	18.41	21.31
2010	13.25	14.61	15.35	16.10	17.32
2020	13.85	14.74	15.23	15.40	16.18
2030	13.82	14.36	14.47	14.61	15.05
2040	14.04	14.10	14.35	14.62	15.33
2050	13.87	14.26	14.37	14.69	14.98
2060	14.17	14.47	14.61	14.91	15.12
2070	14.45	14.51	14.61	14.87	15.00

Table 7.--Marginal costs of production for alternative wood energy production levels for scenario 5: aspen output increasing after 40 years, softwood output constant, and wood energy use primarily a 30-year opportunity

Period midpoint year	Ten-year wood energy production level (Millions of dry tons)			
	10	20	25	30
	ASPEN (Dollars per cunit)			
1980	32.23	31.44	33.40	38.20
1990	35.45	34.76	37.09	43.31
2000	39.83	38.99	41.50	49.07
2010	45.21	44.19	46.64	55.73
2020	44.94	41.99	41.03	40.95
2030	44.62	40.56	38.61	37.01
2040	44.62	39.47	36.51	33.98
2050	43.93	38.89	35.63	32.97
2060	44.25	39.90	37.27	34.54
2070	45.33	39.66	36.64	32.20
	SOFTWOODS (Dollars per cunit)			
1980	38.51	39.39	38.75	39.65
1990	40.10	41.71	41.09	42.52
2000	39.86	41.91	41.21	42.71
2010	39.64	41.46	40.84	42.98
2020	42.97	45.12	44.76	48.70
2030	47.64	49.51	49.32	51.67
2040	50.39	50.54	49.85	51.50
2050	51.42	49.89	48.76	48.06
2060	46.84	43.19	42.89	41.74
2070	44.81	43.53	42.84	41.63
	WOOD ENERGY (Dollars per dry ton)			
1980	14.51	18.16	19.90	21.73
1990	14.69	18.40	20.44	22.65
2000	14.77	18.44	20.75	23.28
2010	13.87	15.77	16.22	16.90
2020	13.87	14.49	14.63	14.70
2030	12.79	12.92	12.96	13.44
2040	12.61	12.80	12.89	13.40
2050	12.53	12.53	12.52	13.23
2060	12.66	12.63	12.45	12.66
2070	12.54	12.52	12.59	13.35

Table 8.--Marginal costs of production for alternative wood energy production levels for scenario 6: aspen output increasing after 40 years, softwood output increasing, and wood energy use primarily a 30-year opportunity

Period midpoint year	Ten-year wood energy production level (Millions of dry tons)		
	10	20	30
	ASPEN (Dollars per cunit)		
1980	29.57	30.16	34.03
1990	31.31	32.51	37.77
2000	33.69	35.80	42.18
2010	37.52	39.92	46.88
2020	38.90	38.55	39.98
2030	38.90	37.60	37.16
2040	40.07	36.78	34.62
2050	40.52	36.24	34.56
2060	40.96	37.38	36.03
2070	42.02	36.98	34.27
	SOFTWOODS (Dollars per cunit)		
1980	42.04	42.48	42.85
1990	45.13	46.00	46.84
2000	46.11	47.24	48.08
2010	46.68	47.91	49.38
2020	50.95	51.75	53.57
2030	55.31	55.57	55.99
2040	56.13	56.00	55.05
2050	52.30	48.87	48.40
2060	46.13	43.15	42.71
2070	44.19	43.95	44.86
	WOOD ENERGY (Dollars per dry ton)		
1980	14.54	18.13	20.25
1990	14.79	18.30	20.98
2000	14.93	18.38	21.57
2010	14.14	16.04	17.18
2020	13.93	15.14	14.89
2030	12.86	12.83	13.55
2040	12.59	12.79	14.05
2050	13.01	14.21	13.87
2060	12.68	12.98	13.10
2070	12.69	12.57	13.57

AN ASSESSMENT OF PRODUCTIVITY AND HARVESTING COSTS FOR VARIOUS FOREST HARVEST SYSTEMS

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Forest residues are increasingly important to forest industry and other economic sectors as well. In northern Minnesota, an area heavily forested and almost totally dependent upon imported fuels, forest residues are a valuable fuel. As part of an effort to analyze the alternatives and opportunities for partially replacing fossil fuels with forest residues in northeastern Minnesota, it was necessary to develop harvest system production and cost data for the Lake States region, emphasizing harvest systems handling small stems and/or logging residues. We extensively reviewed literature dealing with available small log harvest systems, and compiled production and cost data for eight selected harvesting systems. New and used equipment configurations were investigated, with costs calculated per cunit and per million Btu.

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LITERATURE SUMMARY

Generalized conclusions based on an extensive review of literature are as follows:

1. Forest access and tract size characteristics of a stand can limit the type of harvesting system that may be utilized. Generally, if a stand is under 30 acres in size, manual systems are more economical. Most mechanical systems do not reach their minimum cost levels until a tract size of 60-80 acres is attained.

2. Stand volume and average stem diameter are critical factors affecting production and costs, no matter what harvesting system is used. Conventional and integrated systems often require an average d.b.h. of 6-10 inches with expected yields of at least 30-50 tons per acre to be economical. Manual techniques have generally been found to be more economical than mechanical systems in small diameter stands (3-5 inches).

3. In pre- and post-harvesting residue systems, the size of the residue pieces is often the limiting factor. Most studies indicate that pieces averaging less than 2-5 cubic feet are not economical.

4. When logging for conventional products, a highly mechanized, full-tree harvest system is one of the most economical operations. In comparison, manual tree-length systems are more costly (but have lower fixed costs), and are comparable to stump bobtail and shortwood prehauler systems. Full-tree (rather than tree-length) skidding is recommended wherever possible.

5. Many types of highly mechanized operations, with high investment costs, require a high machine utilization rate (generally greater than 60 percent) to function efficiently. This is especially critical for feller-bunchers and whole-tree chippers.

6. For a highly mechanized/high production whole-tree chipping operation operating at woods landing, under optimum conditions, an average (delivered) cost per green ton of $12.31 (1980 dollars) was indicated. Average chip production cost ranged from $9 to a high of $15 per green ton; varying daily production rates were responsible for the cost differences.

7. In most cases, chipping at the harvesting site (woods landing) is more economical than chipping at a central landing, and is comparable to chipping at a mill. Debarking and chipping in the woods appears to be too costly compared to debarking at the mill and is not recommended.

8. A central processing yard (CPY) system offers definite advantages compared to a conventional system. One of the most important is that an increased volume of material is generated which may be used as wood fuel. This increased utilization can offset the higher costs associated with a CPY.

9. Integrated operations that produce conventional roundwood products and whole-tree chips for energy or pulp can be economical. However, the production and sorting of roundwood must not interfere with chip production. For a low cost integrated system, a four-person crew with a medium-sized chipper may have the most potential.

10. Pre-harvesting unmerchantable material for fuelwood has the advantages of potentially increasing conventional harvest productivity and reducing the time and costs of site preparation and regeneration.

11. The economics of post-logging operations which harvest logging residues and residual trees is highly dependent on the volume and size of the biomass. Bunching residues can lower collection costs significantly. Equipment best suited for residue harvest are feller-skidders in large residual trees and low grade stands, and forwarders equipped with a wide trailer and grapple saw, for gathering logging residues that are on the ground. Costs varied considerably between residue harvest studies involving different equipment mixes. Costs ranged from $32 to $75 (1978 dollars) per ODT.

12. Since most harvesting research is limited to a small set of sites, situations, and economic, and environmental constraints, it should be evaluated with caution.

PRODUCTION AND COST DATA FOR 8 HARVEST SYSTEMS

Harvesting Operations

Eight harvesting systems were evaluated to determine production capacity and costs per cunit when operating in typical northern Minnesota forest stands. The harvesting systems included whole-tree chip, whole-tree chip with saw log sort, tree-length logging and tree-length with chipping, and mechanized fell-/manual buck harvesting systems. Table 1 summarizes equipment and labor configurations for each system.

Investment costs for these systems were found to range from $300,000 for the mechanized fell/manual buck system to almost $1 million for the tree-length/chipping system (1983 dollars). Investment costs were based on new equipment unless otherwise specified. Total capital investment costs are listed in table 1.

Production and Cost Inputs

Production rates for individual machines were collected from current literature sources and from equipment manufacturers. These rates were used to determine overall harvest system productivity. Production rates were developed for a range of basal areas (20-140 ft^2 /acre) and diameters at breast height (5, 6, 8, 10, and 12 inches) for northern Minnesota aspen stands. All harvests were assumed to be clearcuts on gently sloping terrain.

Machine costs were developed according to methods described by Miyata (1980). Fixed and operating costs per productive hour[3] were calculated for each machine. Straight line depreciation and an 11.5 percent interest rate were used in the machine rate calculations. Machine and labor utilization rates were assumed to be at average rates (no unusual delays or downtime). Labor

[3] *According to Miyata, a productive hour is that part of scheduled operating time during which a machine actually operates which is based on the machines estimated utilization rate. A scheduled hour is the time during which equipment is scheduled to do productive work.*

Table 1.--Equipment investment cost and personnel requirements for 8 harvest systems

Equipment	Tree-length logging/ chipping	22" Whole-tree sort/chip	22" Whole-tree chip	Mechanized fell/manual buck (3)[1/]	Mechanized tree-length logging	Mechanized fell/manual buck (2)[1/]	18" Whole-tree chip/sort	18" Whole-tree chip
Hahn pulp/logger II limber/slasher	1				1			
Timber jack 30 feller buncher	2	2	2	1	1	1	1	1
John Deere 640 grapple skidder	2	2	2	1	1	1	1	1
22" morbark chipper		1	1					
18" trelan chipper	1						1	1
Cat D40 dozer/skidder (used)	1	1	1	1	1	1	1	1
Chainsaw	2	2	2	8	2	6	2	2
Crew truck	1	1	1	1	1	1	1	1
Maintenance truck (used)	1	1	1	1	1	1	1	1
Fuel truck (used)	1	1	1	1	1	1	1	1
Lowboy (used)	1	1	1	1	1	1	1	1
Total Capital Investment (1983 dollars)	916,803	752,803	752,803	297,177	569,183	296,179	418,183	418,183
Total crew size	9	8	7	10	6	8	5	6

[1/] (3) refers to 3 delimber/toppers and 3 buckers
(2) refers to 2 delimber/toppers and 2 buckers

Table 2.--Harvest system cost per productive hour

System	Machine cost	(Percent of total)	Labor cost	(Percent of total)	Total system cost
Tree-length logging/chipping	286.53	(63)	168.62	(37)	455.15
22" Whole-tree chip/sort	237.54	(63)	141.25	(37)	378.79
22" Whole-tree chip	237.54	(66)	125.06	(34)	362.60
Mechanized fell/manual buck (3)	121.08	(40)	182.28	(60)	303.36
Mechanized tree-length logging	166.72	(61)	107.54	(39)	274.26
Mechanized fell/manual buck (2)	113.38	(44)	145.28	(56)	258.66
18" Whole-tree chip/sort	138.66	(56)	108.28	(44)	246.94
18" Whole-tree chip	138.66	(61)	89.78	(39)	228.44

costs include a base rate of $10.25 (foreman) or $9.25 (laborer) and a benefit package of 40 percent.

Harvesting system costs per productive hour include machine and labor costs (table 2). These figures do not include product transportation costs to the mill, road building costs, stumpage costs, or production quotas.

Each system was assumed to operate 250 days a year for 9 hours each day, giving an estimated 2,250 scheduled hours per year. Total productive hours vary with each machine and system. The large, highly mechanized systems (tree length logging/chipping and 22 inch WTC/sort) were the most expensive per productive hour (up to twice as much compared to the smaller or less mechanized systems, mechanized fell/manual buck and 18 inch WTC).

Harvest System Cost Analysis

Costs per cunit per productive hour were calculated for each harvest system and are summarized in table 3 to compare harvesting systems. The system found to have the highest average cost per cunit is tree length logging/chipping ($42.38). The 18-inch whole-tree chip system ($28.56) is lowest; because of reported problems with small sized chippers due to jamming and to large crowns, the assumed utilization rate for this unit may be unrealistically high (and thus the cost of $28.56 may be a bit low). Assuming that the $28.56 figure is accurate, the harvesting cost for the 22-inch WTC averages $7.38 more per cunit than the 18-inch WTC, due to the high cost of a new chipper. The higher production of a 22-inch system is not enough to compensate for its much higher capital investment.

All systems were extremely sensitive to stand variables. Costs decreased as basal area and/or average diameters increased.

Used Equipment Cost

High investment costs associated with new equipment increase cost per cunit. Most logging firms today utilize used machinery. To investigate the effect of used equipment on cost per cunit data, four systems were reconstructed using used machinery prices. The 22-inch whole-tree chipping, 22-inch WTC with sort, tree-length logging with chipping, and 18-inch whole-tree chipping systems were selected. The new and used equipment prices include total system investment costs (table 4). Total system ivestment costs were lowered by as much as 42 percent.

Used equipment investment costs were used to calculate harvest system cost per productive hour (table 5). Estimates were obtained from equipment dealers in the Lake States and are applicable only to this region. Used equipment was assumed to be approximately 4 years old. Use of used equipment reduced system cost per productive hour by 16.5 percent on the average for the four systems tested, assuming identical operating costs for new and used equipment. However, higher maintenance and repair costs, and/or lower machine utilization rates of used equipment could nullify these savings. To assess the effects of higher operating costs upon the economics of using used equipment, operating costs were varied as follows:

- vary maintenance and repair costs
  25 percent higher
  50 percent higher
  100 percent higher

Table 3.--Summarized harvest system cost/cunit per productive hour

System	Product	Stand basal area (Square feet per acre) / Average diameter (Inches) 40 / 6"	40 / 10"	80 / 6"	80 / 10"	120 / 6"	120 / 10"	Average cost
Tree length logging/chipping[1/]	Pulpwood chips	68.34	37.12	45.93	33.32	38.74	30.80	42.38
22" WTC/sort[3/]	Chips	53.64	37.47	46.38	31.23	44.01	29.38	40.35
22" WTC	Chips	41.60	28.56	35.63	23.80	33.80	22.39	35.94
Mechanized fell/ manual buck (3)	Pulpwood	62.55	21.24	42.07	17.43	35.48	16.13	32.48
Mechanized tree-length logging	Pulpwood	56.55	31.52	28.04	31.52	32.08	31.52[2/]	36.87
Mechanized fell manual buck (2)	Pulpwood	53.33	25.21	37.06	22.30	35.05	20.63	32.26
18" WTC/sort[3/]	Chips	49.68	34.81	42.95	29.01	40.76	27.29	37.42
18" WTC	Chips	38.03	26.36	32.89	21.97	31.25	20.88	28.56

1/ Volume of pulpwood and chips combined.

2/ System reached estimated maximum production due to equipment restraints.

3/ Sixteen percent of total volume processed through system was saw logs. Cost of chips includes cost of bucking out saw logs.

Table 4.--Harvest system costs per productive hour for new and used equipment

System	System cost per productive hour		
	New	Used	Percent
	- - - Dollars - - -		
Tree-length logging/chipping	455.15	375.88	(-17)
22-inch whole-tree chip/sort	378.79	310.13	(-18)
22-inch whole-tree chip	362.60	293.74	(-19)
18-inch whole-tree chip	228.44	201.11	(-12)

- vary machine utilization rate
  5 percent lower
  10 percent lower
  20 percent lower
- vary a combination of
  25 percent higher maintenance and repair with 5 percent lower utilization
  50 percent higher maintenance and repair with 10 percent lower utilization
  Doubled higher maintenance and repair with 20 percent lower utilization.

Assuming identical operating costs for new and used equipment, all systems with used equipment had significantly lower costs per cunit. The 22-inch whole-tree chip system had the lowest average cost of $22.15 per cunit. As operating costs were increased, used equipment cost per cunit approached that of new equipment. Lower utilization rates had a greater effect on costs than the increased maintenance and repair costs used in this comparison. When utilization rates decreased to 20 percent below new, costs per cunit were higher than for new equipment costs except for the 22-inch WTC system. When maintenance and repair costs were doubled, costs per cunit were still under those of new equipment. A combination of 50 percent higher maintenance and repair costs with 10 percent lower utilization rates resulted in per cunit costs approximately equal to those of new equipment (except for the used 22-inch WTC system which was still $6 under new equipment costs per cunit). Therefore, even with relatively high operating costs, used equipment appears to lower costs per cunit compared to systems utilizing new equipment.

Fuel Harvest Computer Program

Further investigation of the harvest system cost data was facilitated through the use of the Fuel Harvest Analysis (FHA) Computer Program developed by Harpole in 1983. The FHA program uses harvest system costs and converts these costs into dollars per million Btu's as recovered from a boiler. The energy costs are computed as a residual and include all costs and revenues that are incurred by harvesting other non-fuel products. Multiple harvest systems may be compared and the lowest cost producing system identified for each harvest unit considered.

In this analysis, 12 harvest units were considered. Each unit was harvested by each harvest system and each harvest system could produce fuel chips. In this data set, estimated stumpage and transportation costs are included with system costs.

Costs per million Btu's ranged from $2.13 to $0.41 (table 6). The whole-tree chip systems with used equipment were the lowest cost systems if volume per acre was low. With larger volumes per acre, the used-tree-length logging/chipping system was the lowest cost system. Note that the same operating costs for both new and used systems are assumed. Higher operating costs for used equipment would change the results.

It is assumed that the used-tree-length logging/chipping system was the lowest cost system due to its

Table 5.--Summarized harvest system average cost/cunit per productive hour for used equipment varying operating cost variables

System	New equipment	Used equipment identical operating costs	Higher maintenance and repair costs			Lower utilization rates			Combination		
			25 percent	50 percent	Doubled	5 percent	10 percent	20 percent	25/5 percent	50/10 percent	Double/20 percent
Tree-length logging/chipping	42.38	35.00	35.95	36.90	38.81	37.15	39.68	46.27	38.18	41.91	51.63
22" whole-tree chip/sort	40.35	33.04	33.67	34.30	35.56	34.86	36.99	42.48	35.54	38.45	45.97
22" whole-tree chip	35.94	22.15	25.55	26.05	27.06	26.41	28.01	32.13	26.95	29.18	34.93
18" whole-tree chip	28.56	25.11	25.59	26.07	27.38	26.60	28.34	32.88	27.11	29.47	35.60

Table 6.--Summary of fuel harvest program output

Unit number	Harvest unit		Least cost harvest system	Cost/mmBtu
	Basal area	Average d.b.h.		
1	40	6	Used--18" WTC	2.13
2	40	8	Used--18" WTC	1.61
3	40	10	Used--Tree-length logging/chipping	1.60
4	40	12	Used--Tree-length logging/chipping	1.22
5	80	6	Used--22" WTC	1.87
6	80	8	Used--22" WTC	1.40
7	80	10	Used--Tree-length logging/chipping	.73
8	80	12	Used--Tree-length logging/chipping	.89
9	120	6	Used--Tree-length logging/chipping	1.70
10	120	8	Used--Tree-length logging/chipping	.67
11	120	10	Used--Tree-length logging/chipping	.41
12	120	12	Used--Tree-length logging/chipping	.59

multiproduct output. With larger volumes per acre, pulpwood revenue offset fuel chip cost. With low volumes per acre, it appears to be cheaper to produce chips only.

Both "cost per cunit" and "cost per Btu" analyses, identify whole-tree harvesting systems as the lowest cost systems. The FHA program picked the used tree-length logging (pulpwood or saw log)/chipping (fuel chips) system with higher volumes per acre because high value products (pulpwood or saw log) would be produced with the fuel chips. The revenue from these products offsets the fuel chip cost. The mechanized fell/manual buck systems were not considered by the FHA program because fuel chips were not produced.

SUMMARY AND CONCLUSIONS

Production and cost were estimated for eight harvesting systems based on the literature for a range of basal areas and average stand diameters for typical northern Minnesota aspen stands. Machine costs were calculated according to standard methods. Harvest system costs per cunit per productive hour were calculated using both new and used equipment investment costs.

An 18-inch whole-tree chip system was found to yield the lowest average cost per cunit for systems based on new equipment ($28.56). High equipment prices increased system costs for the large mechanized systems. The highest cost per cunit was incurred by a tree-length logging chipping system ($42.38). Adding sorting capabilities to tree-length logging and whole-tree systems added an average of $6.26 to cost per cunit. All system costs varied significantly with changes in either basal area or average d.b.h.

When used equipment costs were substituted for new machine costs, the 22-inch whole-tree chip system had the lowest cost per cunit of four systems studied ($22.15). Used equipment investment costs lowered harvest system equipment costs an average of 40 percent. Operating costs were varied for the used machines to determine the effects of higher operating costs on system cost per cunit. Used equipment yielded lower costs per cunit than comparable new systems even considering 50 percent higher maintenance and repair costs, and a 10 percent lower machine utilization rate. Both new and used system costs were evaluated to determine costs per mmBtu using the Fuel Harvest Computer program. The tree-length logging/chipping system was the lowest cost system. Costs ranged from $2.13 to 0.41 per mmBtu.

Future harvesting research will concentrate on biomass harvesting and small-scale logging problems and opportunities.

FUTURE MARKET UNCERTAINTY: A CASE FOR SHORT-ROTATION SYSTEMS[1]

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Aspen (*Populus tremuloides Michx. and Populus grandidentata* Michx.) has only recently been in great demand in northeastern Minnesota. Although the aspen supply in the region is currently abundant, a shortage could develop because of the imbalanced age distribution of aspen. Today's forest contains many financially mature and overmature aspen stands and few young aspen stands because few stands have been cut, and without cutting, aspen has not regenerated well. High aspen demand coupled with decreases in aspen supply after the currently mature aspen stands are cut could greatly increase aspen prices. However, changes in utilization standards could also shift some aspen demand towards lower value hardwoods and thus tend to keep aspen prices down. The utilization research and development efforts that led to increased aspen demand were stimulated by the relative abundance and low price of aspen. A similar series of events could unfold around the lower value hardwoods if aspen prices increase significantly. That would greatly affect wood energy use because the lower value hardwoods, of all species groups, have the greatest potential for such use. The future aspen supply is thus a critical issue.

INCREASING ASPEN SUPPLIES

Two possible alternatives for increasing aspen supplies are: (1) introducing short-rotation hybrid poplars (*Populus* hybrids) and (2) conducting timber stand improvement work on overmature and unmarketable existing aspen stands.

Hybrid poplar systems have been recently developed that can produce merchantable size material in 10 to 15 years. Economic analyses using current aspen prices for product price indicate that the systems' financial performance appears marginal at best (Rose *et al.* 1981, Lothner *et al.* 1981, Ferguson *et al.* 1981). However, these analyses also indicate that financial performance is extremely sensitive to product price.

Timber stand improvement work on overmature and unmarketable aspen stands simply involves clearing the stand to stimulate natural aspen regeneration. Both the Superior National Forest and the Minnesota Department of Natural Resources are seriously considering implementing this type of work on a large scale in the next 10 years. This alternative is quite expensive, and most management costs occur immediately. Considering the uncertainty of long-range demand fore-

[1] *The study was supported in part by the Oak Ridge National Laboratory, U.S. Department of Energy.*

[2] *The research was done while Dr. Hoganson was a Principal Economist with the U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Duluth, Minnesota.*

casts, such regeneration work may be unnecessary. Postponing present regeneration decisions and possibly introducing short-rotation alternatives at some intermediate time might be a more viable alternative. Both the lack of data and the relation of regeneration decisions to other management decisions complicate analyses of regeneration alternatives. We will compare a short-rotation hybrid poplar system with one method of stand clearing to stimulate aspen regeneration. The purpose of the comparison is to examine a potential advantage of short-rotation systems resulting from an uncertain future timber market.

REGENERATION DECISIONS AND UNCERTAINTY

The many authors focusing on uncertainty in forest management agree that much uncertainty exists, it cannot be eliminated, and therefore, it must be recognized in the decisionmaking process. Several authors suggest using quantitative techniques for forestry decisionmaking under risk and emphasize the need to view planning as a continuous process in which revising and updating are the general rule (Marty 1964, Thompson 1968, Thompson 1972, Fight and Bell 1977, and Hassler and Sinclair 1982). The overall goal must be to select flexible management alternatives that will perform well under a wide range of possible outcomes. Carder and Oglesby (1973) state that the need for maintaining flexibility is evident in the language used in national forest guidelines, directives, and regulations. Phrases such as "manage the present to insure the future," "avoid irreversible mistakes," and "keep options open" are quite common. Fight and Bell (1977) indicate that the USDA Forest Service has maintained flexibility by carrying a large inventory. Although a large inventory allows for flexibility in future harvest levels, such a policy is usually expensive. Short-rotation systems might allow forest managers to maintain this flexibility at a much lower cost.

What to plant, how much to plant, where to plant, and when to plant are all important regeneration issues for a forest as a whole. These issues depend heavily on current harvest decisions, resources available, and future market conditions. The uncertainty surrounding future market conditions, specifically future market prices and future consumption levels, makes it difficult to evaluate alternatives. Yet strategies are being formulated and implemented today to produce wood for future periods. Regeneration activities implemented are generally irreversible and have high front-end costs. The uncertainty of future market conditions must be recognized in developing strategies. Unfortunately, the complexity and size of the overall management system make it difficult, if not impossible, to recognize market uncertainty explicitly when examining the system as a whole.

One simple way of examining just the regeneration decision is to view it as a problem in which we are forced to decide today how much wood to produce for a future time under uncertain future timber prices. Figure 1 illustrates the uncertainty surrounding future prices and a potential advantage of short-rotation systems. In year 0 we are at point P, and the two-dimensional "cone" with vertex point P represents all of the possible future real prices. The convex-shaped boundaries of the cone represent the maximum and minimum exponential rates for price changes. At the time of harvest, H, the "cone" could be quite wide. With short-rotation systems we could postpone the regeneration to approximately year ½ H and still produce timber volumes in year H. A "cone" can also be constructed to describe the future price uncertainty when the short-rotation system is implemented. It is illustrated in figure 1 by the "cone" with its vertex at point F. Conceptually

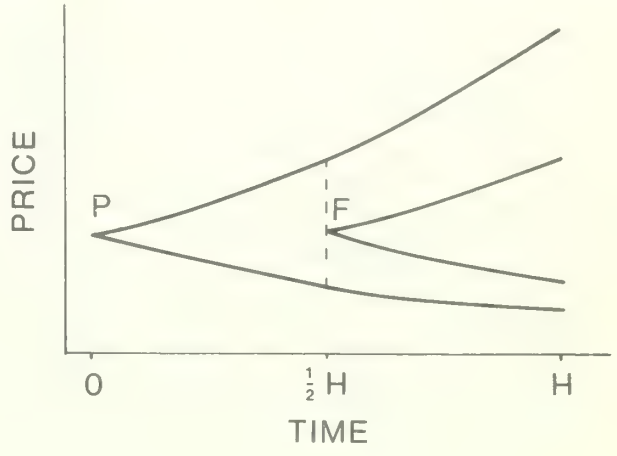


Figure 1.—*The "cones" of price uncertainty for two regeneration alternatives. The "cone" with the vertex at point P represents the range of market prices from the present to period H that sellers might expect if they decide to invest in a conventional management system in period zero. The "cone" with the vertex at point F represents the range of market prices from period ½ H to period H that sellers might expect if they postpone their investment decision until period ½ H and then invest in a short-rotation system. The inner cone is one of a family of identically shaped cones with vertices positioned along the broken line. The difference in width of the two "cones" illustrates the price uncertainty that could possibly be overcome by delaying the regeneration decision until ½ H when prices in period H might be less uncertain.*

Table 1.--The dollar value and timing of expeditures and receipts of two management systems for producing initial yields in year 30 [1/]

Management system	Expenditure and receipt items	Values/acre (Dollars)	Years
Aspen	Land purchase	100.00	0
	Site preparation	135.00	0
	Administration	7.50	0
	Full tree harvest	740.00	30,60
	Product sale (41.0 dry tons X $25.00) [2/]	1,025.00	30,60
	Land sale	100.00	60
Short-rotation poplar	Land purchase	100.00	15
	Site preparation	385.00	15
	Site preparation	35.00	16
	Planting	60.00	16
	Administration	7.50	15,16
	Cultural tending	14.00	17
	Full tree harvest	850.00	30,45
	Product sale (47.25 dry tons X $25.00)	1,181.00	30,45
	Full tree harvest	740.00	60
	Product sale (41.0 dry tons X $25.00)	1,025.00	60
	Land sale	100.00	60

1/ Metric equivalents: 1 acre = 0.405 ha; 1 dry ton = 0.90 metric tons.
2/ For illustration purposes, a $25.00 per dry ton product value was used in this table. In our analyses, we changed price at average annual rates ranging from -1 percent to 3 percent from this $25.00 base price.

Source: Basic data taken from Rose et al. (1981) and information on file with the Superior National Forest (modified by authors to reflect the forestry situation in northern Minnesota).

speaking, the size of the two "cones" illustrates the price uncertainty that could be overcome by delaying production decisions until year ½ H when prices in year H should be less uncertain. The broken line in figure 1 indicates the locus of possible vertices for the inner cone.

COMPARISON OF TWO SYSTEMS

We will compare a short-rotation hybrid system recommended by Hansen *et al.* (1983) to a stand clearing system for stimulating natural aspen regeneration. Table 1 shows the general cash flow information for the two systems. The stand clearing system is being evaluated for implementation by the Superior National Forest (table 1). Cost information for the short-rotation system was obtained from Rose *et al.* (1981), and the system was modified slightly to reflect the forestry situation in northern Minnesota. Specific silvicultural detail of the two systems are incidental to our purpose. We assume that an overriding goal is to produce wood in year 30. The starting times of the two systems are staggered. The aspen system is initiated immediately; the hybrid poplar system is initiated in year 15. In this way, both systems produce their largest discounted return in year 30. Additional rotations for both systems are included to recognize the advantages of an established root stock with both hybrid poplars and aspen. The financial measure to use for comparing systems depends on the situation faced by management. We chose the internal rate of return (IRR) because available capital is the most limiting resource in many cases. The net discounted benefit per unit of timber produced might also be an appropriate measure because the level

of demand is often the limiting factor for a region as a whole. Both IRR and the net discounted benefit per unit of timber produced are relative measures. Results with each would be quite similar. The land values used in the analysis reflect values for use other than timber production, and thus, the fact that the values are equal for both alternatives does not imply that the alternatives involve the same site or even equivalent sites in terms of timber production. We assume that both sites are at equal distances to market only to eliminate any locational effect for the comparison. Land costs are not assumed for the SRIC system until year 15 because land is available, and no commitment is necessary until year 15. A primary advantage of the SRIC system is that decisions on whether or not to implement it can be delayed until year 15 when more information is available concerning future prices as well as other potential systems that might be developed in the mean time.

The financial performance of both systems is very sensitive to timber prices. Assuming that the current $25 per dry ton market price remains stable, neither system appears to be a wise investment because both earn rates of return less than 4 percent, the alternative rate of return used by the Forest Service (Row *et al.* 1981). However, increasing timber prices relative to other management expenditures have a dramatic positive impact on the IRR for both systems.

Predicting future prices is extremely difficult. We assume a probability distribution on future prices to illustrate a point about uncertainty. Before a definite decision can be drawn about the overall value of either system, a more thorough analysis would be needed to examine the sensitivity of results to the distribution assumed, other sources of uncertainty, and other related management issues. We assume that the average annual real price increase for the next 30 years can be described by a triangular distribution with a most likely price increase of 1 percent, a maximum price increase of 3 percent, and a minimum of – 1 percent. After year 30, we assume real prices will remain constant. Using $25 as today's price, we translate this into real prices ranging from $18.50 to more than $60 per dry ton in year 30. Although this might appear to be a wide range, timber prices for other species are already significantly above $60 per dry ton. Our "cone of uncertainty" surrounding future timber prices is shown in figure 2.

With the aspen system, actions must begin today to produce wood for year 30. Much risk is involved because of the large cost (commitment) initially involved. Given the probability distribution for price changes and the price at the time of the initial investment, we can estimate the probability distribution for the financial performance measures. Figure 3A shows the uncertainty surrounding IRR for the aspen investment. If 4 percent is the alternative rate of return, then a decision on

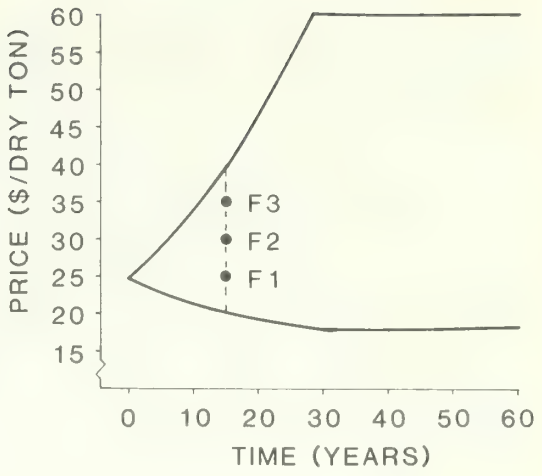


Figure 2.—*The "cone" of price uncertainty stemming from a present-day price and future price assumptions. The "cone" is described by a triangular distribution with a most likely annual price increase of 1 percent, a maximum annual price increase of 3 percent, and a minimum of – 1 percent. The broken line represents the locus of possible prices in year 15. Points F1, F2, and F3 on the line represent annual price increases of 0, 1, and 2 percent, respectively.*

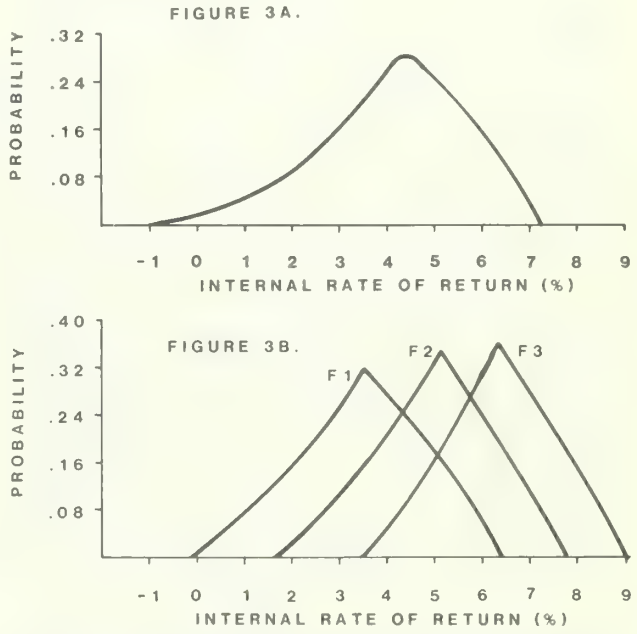


Figure 3.—*The probability distribution of the IRR for: (A) a natural regeneration system and (B) a short-rotation hybrid system. Each IRR distribution is derived assuming a triangular probability distribution of real annual average price increases with a most likely price increase of 1 percent. In figure 3B a probability distribution is shown for each of three plausible prices (F1, F2, and F3, see figure 2) for year 15, the year of critical investment.*

whether to undertake the traditional alternative would be difficult. Rates of return range from −1 percent to 7.25 percent with a mean very close to 4 percent.

With the short-rotation hybrid system, decisions can be delayed until year 15 and yet wood can still be produced in year 30. Based on our assumption describing real price increases, a new cone will be formed in year 15 with its vertex at the year-15 price. This price will not become known until year 15. For our comparison we considered three plausible prices for year 15—$25, $29, and $33.50. These prices represent 0-percent, 1-percent, and 2-percent average annual increases over the first 15 years. For each of these plausible year-15 situations (points F1, F2, and F3 in figure 2), probability distributions were calculated for the IRR from investing in the short-rotation hybrid system in year 15. These calculations used the same price increase assumptions that were used to calculate the IRR probability distribution for the aspen system. Figure 3B shows the distributions on IRR for the 3 year-15 prices considered. The distributions are narrower than for the aspen system. Also, these distributions do not all center near the 4-percent alternative rate of return. For point F3, the obvious decision would be to invest; the downside risk is minimal because there is very little risk of a return of less than 4 percent. For points F1 and F2, the choice is not as obvious, but most decisionmakers who use an alternative rate of return of 4 percent would probably invest at point F2 and not invest at F1.

To examine the ability of delaying decisions until year 15, we used probabilities for F1, F2, and F3 occurring and developed a single IRR distribution for the SRIC alternative. Probabilities were derived by dividing the triangular distribution on the price trend for the first 15 years into three discrete regions so that the region means corresponded with the price increases assumed for cases F1, F2, and F3. The break points in the triangular distribution were price increases of ½ percent and 1½ percent. The probabilities of F1, F2, and F3 were calculated as 0.28125, 0.4375, and 0.28125, respectively. With F1 occurring, it was assumed that the 4-percent alternative rate of return would be selected; the SRIC alternative was selected for outcomes F2 and F3. The resulting distribution is shown in figure 4. The distribution represents the probabilities of SRIC outcomes as viewed in year 0. It is only an approximation of the actual distribution because means of the discrete regions of the price trend distribution were used in deriving it. A Monte Carlo simulation method could be used to derive better estimates, but considering the lack of precision surrounding the estimates of future price trends, there is little need for a more precise estimate of the IRR distribution. The real significance of the distribution shown in figure 4 is the relatively low probability of a return less than the assumed 4-percent

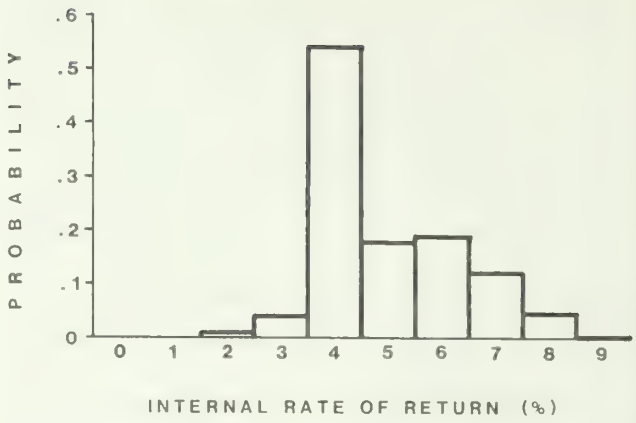


Figure 4.—*The probability distribution of the IRR for the short-rotation alternative. The distribution is only an approximation. It was derived by considering the three cases shown in figure 3B. For the lowest level price, the decision is to invest at the 4-percent alternative rate; the SRIC alternative was chosen for the other two cases.*

alternative rate of return. The ability to delay decisions thus reduces downside risks.

DISCUSSION

Although we looked at specific investment costs and returns in our comparison, it is not difficult to generalize somewhat. Applying the same SRIC system on a more expensive site would be a good example. For this case, the net impact would shift the IRR distributions of figure 3B to the left, and this shift might cause the decision in year 15 to be invest only if outcome F3 occurs. The major impact on the IRR distribution shown in figure 4 would be an increase in the probability of a 4 percent return (no investment) and a decrease in the probability of higher returns. The downside risk would not be affected significantly.

We assumed that future prices are independent of the regeneration decision. Obviously, for large landowners they are not. Demands for timber products are very inelastic. Therefore, changes in the general market supply (regeneration level) can significantly influence market price, but influence the consumption level very little. From the public's viewpoint, this means that it is expensive to carry a surplus inventory to overcome uncertain future demands; additional regeneration work results in only a small increase in the consumption levels. Intuitively we might think that any surplus inventory in one period could be used in the next period. To a certain extent this is true, but we must also remember that regeneration work has already been completed to produce supplies for periods far into the future. In other words, once a large inventory develops, it is not easily reduced because of the time lag involved

within the total forest management system. A partial reliance on shorter rotation species might lead to much greater flexibility.

The uncertainty surrounding future timber prices makes it extremely difficult to evaluate specific management alternatives on specific sites. Definite answers are seldom possible. A recent trend in the Forest Service is to take a much more systematic approach by considering all stands in an entire forest together by using a large linear programming model. These models are very useful in that they can help put the management of specific stands into perspective with the management of other stands and the goals for the forest. One major shortfall of these planning models is their inability to recognize the uncertainties surrounding model inputs, including price uncertainty. By ignoring uncertainty, the large-scale planning models are not recognizing the differences in flexibility between different model alternatives. Consequently, models of this type are not appropriate for evaluating the full potential of short-rotation alternatives. The complexity of forest management decisions makes it impossible to obtain a complete picture from a single model. Decisionmakers must recognize the limitations of each quantitive technique they use. A real challenge they face is to synthesize the results from available models and add their own judgment about concerns not adequately described in the modeling process.

In our example, we ignored uncertainties surrounding variables other than price used in our cash flow analyses (table 1). Simulation approaches like those proposed by Hertz (1964) might be more appropriate for examining the current state of uncertainty surrounding specific alternatives. We would expect that distributions surrounding returns are wider when all types of uncertainty are considered. But let's not forget that some of this uncertainty could be overcome through research and experience. The short-rotation system used in our example already exists. If regeneration can be delayed for 15 years, as in our example, perhaps even better systems can be developed before implementation is necessary.

CONCLUSIONS

When future timber demand levels or future timber prices are uncertain, short-rotation systems can allow forest managers to delay or postpone some investment decisions. As more information becomes available on future market conditions, it can be used to evaluate the need for additional investments. This approach reduces the likelihood of making unprofitable or unnecessary investments.

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ESTIMATING WOOD ENERGY DEMAND IN NORTHEASTERN MINNESOTA

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Estimates of potential wood energy demand in northeastern Minnesota were needed for two purposes: First, the timber supply study by Hoganson required wood energy demand estimates to add to the demand projections for other forest products; second, Lichty *et al.* needed estimates of the size of a potential wood energy industry to measure regional economic impacts.

Estimating wood energy demand required three steps. First, using a 1977 input/output model of the study region we estimated the volume and cost of existing fossil fuel use for 31 key energy-using sectors. Second, we calculated the green tons of wood fuel required (as well as any cost savings generated) to replace a unit of coal, oil, or natural gas. Using a spreadsheet, we related (1) BTU content, (2) combustion efficiency, and (3) price of coal, oil, gas, dry wood pellets, green chips, and air-dry roundwood to determine the volume and costs of green wood required to replace a unit of any fossil fuel. Third, we used a second spreadsheet to combine current fossil energy use, wood conversion scenarios, and the wood volume and costs needed to replace each unit of fossil fuel scheduled for conversion. The result of this third step, when summed over all sectors, shows the total wood volumes and costs of replacing fossil fuels. These data were then conveyed to Hoganson and Lichty for their purposes.

CURRENT FOSSIL FUEL CONSUMPTION (1977)

Using a 1977 input/output model of the northeastern Minnesota economy, coal, petroleum, and natural gas purchases were examined. Of 223 sectors, 31 used 97 percent, 89 percent, and 95 percent of all coal, oil, and natural gas purchased in the region. These 31 sectors form the basis for estimating future wood energy demand scenarios.

Using fuel price data by sector grouping (table 1), we then converted these fossil fuel purchases into physical volumes and BTU contents (table 2).

Table 1.--Assumed fuel prices by sector group, 1977

(In dollars per million Btu's as fired)

Fuel	Sector group				
	Housing	Commercial	Industrial	Transport	Utility
Coal	3.0100	0.9540	0.9540	0.9540	0.6946
Fuel oil	3.1957	2.9375	2.7571	3.2893	2.6292
Natural gas	2.1384	1.7189	1.1263	1.2396	1.0946
Wood pellets	2.1875	2.1875	2.1875	2.1875	2.1875
Wood chips	.8865	.8865	.8865	.8865	.8865
Roundwood	.9259	.9259	.9259	.9259	.9259

Table 2.--Base-line fossil fuel consumption in 1977 by volume and energy content

Sector	Volume			Energy content			
	Coal (Tons)	Fuel oil (Thousand gallons)	Natural gas (Million cubic feet)	Coal	Fuel oil	Natural gas	Total Btu's
				(Million Btu's)			
Iron mining	186,452	54,563	16,580	4,685,535	7,638,823	16,579,952	28,904,310
Highway construction	0	5,736	1	0	803,018	888	803,906
Well drilling	0	30,042	0	0	4,205,868	0	4,205,868
Maintenance	83	6,998	7	2,096	979,653	7,103	988,852
Meat products	1,543	811	174	38,784	113,525	174,021	326,330
Milk products	1,668	1,728	107	41,929	241,921	107,431	391,281
Frozen fruit and vegetables	0	1,826	258	0	255,703	258,368	514,072
Logging and sawmill	17,853	14,376	24	448,637	2,012,622	23,972	2,485,232
Pulp and paper	202,427	34,954	4,072	5,087,002	4,893,548	4,071,739	14,052,289
Chemicals 1	4,839	1,816	287	121,593	254,253	286,780	662,626
Chemicals 2	751	2,876	1,236	18,868	402,597	1,235,905	1,657,370
Chemicals 3	1,585	2,262	58	39,832	316,637	57,711	414,180
Petroleum refining	8,718	57,480	1,823	219,078	8,047,224	1,822,783	10,089,084
Asphalt and pavement	3,003	9,788	70	75,472	1,370,280	70,141	1,515,893
Miscellaneous stone	2,294	1,946	465	57,652	272,388	465,240	795,280
Blast furnaces	77,584	1,402	522	1,949,686	196,221	522,063	2,667,970
Railroads	0	14,480	178	0	2,027,179	178,283	2,205,462
Trucking	0	2,906	5	0	406,773	4,840	411,614
Water shipping	83	2,547	9	2,096	356,611	8,874	367,581
Electric utility	984,973	36,323	4,868	24,752,375	5,085,197	4,867,532	34,705,104
Gas utility	0	182	19,933	0	25,483	19,933,309	19,958,792
Wholesale trade	250	8,117	73	6,289	1,136,340	72,721	1,215,351
Retail trade	1,043	9,116	419	26,205	1,276,255	419,454	1,721,915
Real estate	0	5,452	194	0	763,234	193,729	956,963
Hotels	0	1,656	130	0	231,830	130,316	362,146
Restaurants	0	163	87	0	22,809	87,265	110,074
Health services	1,752	3,589	182	44,025	502,468	181,511	728,005
Government enterprise	29,407	3,052	568	738,994	427,234	568,387	1,734,615
Households	5,513	87,805	6,611	138,538	12,292,768	6,610,550	19,041,857
Federal government	4,088	6,125	119	102,725	857,532	118,681	1,078,938
State and local government	5,464	14,750	2,023	137,317	2,065,021	2,022,805	4,225,143
Total	1,541,374	424,864	61,082	38,734,729	59,481,015	61,082,355	159,298,099

WOOD CONVERSION SCENARIOS

To develop future fuel use scenarios, we estimated the amount of fossil fuels that might be displaced by wood. While the ultimate causes for the displacement are unknown, they will probably result from a combination of factors, such as fuel price differences, government tax policies, and perceived fossil fuel shortages.

As one might expect, different energy users face different problems and opportunities when converting to wood fuels. For each sector, we first tried to define the maximum opportunity for substituting wood fuels for fossil fuels. Once this maximum level was established, we then developed two more likely possibilities which were then followed through the analyses.

There are two major categories of users in the input/output model: (1) industries and businesses that make, distribute, or service all of the products the economy needs; and (2) so-called "final demand" users, consisting of households, government, and exports that absorb the final outputs of industries and businesses.

The industrial portion of the input/output model is divided into about 200 sectors. But if we include only those sectors purchasing more than $1,000,000 of energy (1977 prices), the resulting 28 sectors account for over 90 percent of all energy use. Thus, only the fossil fuel demands of these 28 industrial sectors were used in developing the two wood energy displacement scenarios.

The final demand portion of the input/output model was divided into households, State and local government, and Federal government, bringing the total number of energy-using sectors to 31.

INDUSTRIAL USE

Coal

Cost and convenience aside, there is probably no technical reason why most coal use could not be entirely displaced by wood. The blast furnace sector, which uses coal to produce coke for the smelting process, is an exception. All other coal use, including that of electric utilities, could be replaced by wood.

Natural Gas

Like coal users, most natural gas users could substitute wood. The primary exceptions are the iron mining, pulp and paper, and blast furnace sectors, which burn large quantities of natural gas to dry taconite pellets, dry paper, or smelt ore. We assumed that no more than 20 percent of the natural gas consumption for these sectors could be replaced by wood. (This assumption has recently been proved wrong; a major taconite pelletizer has installed a wood burning system with apparent success.)

Other exceptions include the chemicals, petroleum refining, and gas utility sectors, which use natural gas both as process energy and as feed stock. It seems highly unlikely that these industries will reduce consumption of a fuel that they themselves produce and that is, in fact, their main raw material or a very close adjunct. For these sectors, we assumed that no natural gas consumption would be replaced by wood.

We assumed that all remaining industries could convert no more than 80 percent of their natural gas consumption to wood. The balance would be consumed in nonseasonal uses such as water heating, where it would be difficult for wood to displace natural gas.

Petroleum (Fuel Oil)

Estimating the potential for petroleum replacement by wood is complicated by the fact that available data do not permit a precise division of petroleum use into space heat, process heat, and transportation. While it was possible to estimate the ratio of space and process heat to total petroleum use for *all* industries, we were forced to make crude estimates for specific industries.

Petroleum use by the iron mining sector in northeastern Minnesota is predominantly for diesel-powered trucks and trains. Thus, we assumed that only 10 percent of its petroleum use could be replaced by wood. The construction, logging, miscellaneous stone, transport, and wholesale trade sectors were treated similarly.

On the other hand, many sectors (food processing, retail trade, real estate, lodging, restaurants, hospitals, State and local enterprise) have a relatively small transportation segment, and we assumed that these sectors could replace up to 75 percent of their petroleum consumption with wood. Seventy-five percent is approximately the statewide average fuel oil heating proportion of total petroleum consumption by the commercial sector.

Two other major industries consuming large quantities of petroleum—pulp and paper and electric utilities—have an even smaller transport use. Thus, we assumed that these two sectors could convert up to 90 percent of their fuel oil use to wood.

The remaining sectors, petroleum refining, paving and asphalt, blast furnaces, and gas utilities, were assumed to make no petroleum conversion to wood fuels, either because they need high-quality energy sources for their processes, or because they are so closely associated with the petroleum industry that conversion is unlikely. (Here, too, the assumption that paving and asphalt users will not use wood or other nonpetroleum fuels has recently been proven wrong.)

FINAL DEMAND USE

Coal

We assumed that the household, State and local government, and Federal government sectors could convert 100 percent of their coal consumption to wood.

Natural Gas

While we assumed that the gas utility sector would convert none of its inputs to wood (although it is conceivable that wood can be gasified and marketed through normal pipelines), the final demand sectors could convert some of their gas use to wood. We assumed that only that portion of gas used for space heating would convert—that is, the seasonal gas use to heat homes, not the year-round use to heat water or dry clothes. Based on data from the Duluth Water and Gas Department, we assumed that this limit was 75 percent for all residential gas consumption and 80 percent for governmental gas consumption.

Petroleum (Fuel Oil)

Here, too, we had difficulty estimating the space heat and transport components of petroleum use. Based on national statistics and some simple ratios, we estimated that Minnesota households use about 55 percent of their total petroleum consumption for home heating. The balance is for transportation and other uses.

For the government sectors, we assumed that petroleum use parallels the commercial sectors already mentioned. Thus, no more than 75 percent of government fuel oil use can be replaced by wood.

Table 3 shows the upper limit on wood fuel conversions by fuel type (coal, fuel oil, natural gas) and by sector. The limits are expressed as a percent of 1977 fossil fuel use.

Given these maximum "possible" levels, we then developed two wood conversion scenarios to be used by both Hoganson and Lichty. Instead of trying to predict how *each* sector might switch, we grouped sectors by (1) the level of certainty surrounding our guess and (2) the predicted rate of conversion to wood.

Table 3.--Maximum wood fuel substitution rates by fossil fuel and sector

(In percent)

Sector	Coal	Fuel oil	Natural gas
Iron mining	100	10	20
Construction	100	10	80
Food processing	100	75	80
Logging and sawmill	100	10	80
Pulp and paper	100	90	20
Chemicals	100	0	0
Petroleum refining	100	0	0
Asphalt and pavement	100	0	80
Miscellaneous stone	100	10	80
Blast furnaces	0	0	20
Transport	100	10	80
Electric utility	100	90	80
Gas utility	100	0	0
Wholesale trade	100	10	80
Retail trade	100	75	80
Real estate	100	75	80
Hotels	100	75	80
Restaurants	100	75	80
Health services	100	75	80
Government enterprise	100	75	80
Households	100	55	75
Federal government	100	75	80
State and local government	100	75	80

Sector group	Level of certainty	Rate of conversion to wood
1. Forest industries and public sectors	High	High
2. Households	High	Low, conversions already extensive
3. Petroleum and gas utilities	High	None
4. Manufacturing and commercial sectors	Low	Moderate
5. Electric utilities and iron mining	Low	Two conversion levels were assumed: 15 percent 25 percent

It is highly likely that both the public and the forest industry sectors will make significant wood conversions by the year 2000, because of the political and economic sense it makes. Households in northeastern Minnesota have already achieved a 25 to 30 percent conversion and will continue to convert if fossil fuel costs continue to rise and wood becomes more convenient to burn. However, the rate of conversion probably will slow. The petroleum, gas utility, and related sectors will make almost no use of wood or other biomass fuels for obvious reasons. Commercial and industrial sectors (excluding iron mining) face an uncertain conversion future. While there are now and will continue to be economic incentives for them to use more wood fuels, many factors make guessing difficult. However, because their combined impact is small relative to the others, it makes little difference what level we assume.

The two sectors that could have the greatest impact—electric utilities and iron mining—also have the most uncertain rates of conversion from coal to wood for producing electricity. These two sectors dominate our scenarios; for example, in Scenario 1 we assumed a 15 percent conversion of coal use to wood, and in Scenario 2 we assumed a 25 percent conversion (table 4).

WOOD FUEL REQUIREMENTS PER UNIT OF FOSSIL FUEL REPLACED

Determining the quantity and cost of wood to replace any fossil fuel requires several kinds of data: (1) energy content, (2) combustion efficiency, (3) wood fuel preference, and (4) prices. The first two, energy content and combustion efficiency, interact to determine the amount of usable energy produced by the burner. Both vary widely even within the same fuel type and within the same kind of furnace. Table 5 shows the values assumed in this study.

The usable burner output is the appropriate benchmark for comparing different fuels, for it is at this point that a user must compare costs. Burner output is simply the product of unit energy content and combustion efficiency. An extra calculation for wood fuels was required, however. Because one of our objectives was to calculate the impact of wood fuel use on forests, we needed to know the green tons of wood required to produce a unit of wood fuel, as burned. For roundwood this ratio is 1 to 1. But because varying degrees of drying occur when wood is chipped or pelletized, the tons of green wood input vary.

Next, we assumed different users would prefer their wood fuels in different forms: green roundwood, slightly drier green wood chips, or very dry wood pellets. Table 6 shows these wood fuel preferences by sector group.

Finally, the data in tables 1, 5, and 6 were combined to produce tables 7, 8, and 9 to be used in the final spreadsheet: table 7 shows the *tons of green wood required per unit of fossil fuel* by fossil fuel and sector group. Table 8 shows the *fuel costs per million Btu* by fuel and sector group. Table 9 shows the *dollars of wood fuel required to replace a dollar of fossil fuel* by fossil fuel and sector group.

WOOD REQUIREMENTS AND COSTS, FOSSIL FUEL BALANCE

We can now calculate the green wood tonnage and cost required as well as the fossil fuel balance and any fuel cost savings if the two wood energy demand scenarios shown in table 4 are achieved. Tables 10 through 13 show the results of Scenario 1. Tables 14 through 17 show the results of Scenario 2. Costs assume 1977 prices.

Achieving either scenario would reduce overall coal consumption by 28 or 35 percent, oil consumption by 23 or 24 percent, and natural gas consumption by 16 or 17 percent. In turn, annual wood requirements would increase 4.3 or 4.7 million green tons. This volume is about 38 percent of the current wood consumption for all purposes in the entire State.

At 1977 prices, these wood volumes would cost $46 or $51 million. In contrast, total fossil fuel costs would decline to $218 or $215 million, cuts of $61 or $65 million—about 22 percent. Thus, net fuel cost savings in the region under these two scenarios would be roughly $15 or $14 million—about 5 percent of total regional fuel costs at 1977 prices. Net fuel cost savings decline with the larger fossil fuel conversions of Scenario 2 because the largest conversions are coal to wood and coal currently costs less than wood.

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Table 4.--Assumed fossil fuel to wood conversion scenarios

(In percent)

Sector	Coal		Fuel oil		Natural gas	
	Scenario		Scenario		Scenario	
	1	2	1	2	1	2
Iron mining	15	25	5		10	
Highway construction	50		5		40	
Well drilling	50		5		40	
Maintenance	50		5		40	
Meat products	50		35		40	
Milk products	50		35		40	
Frozen fruit and vegetables	50		35		40	
Logging and sawmill	80		10		40	
Pulp and paper	80		80		10	
Chemicals 1	25		0		0	
Chemicals 2	25		0		0	
Chemicals 3	25		0		0	
Petroleum refining	25		0		0	
Asphalt and pavement	25		0		0	
Miscellaneous stone	25		10		40	
Blast furnaces	0		0		10	
Railroads	50		5		40	
Trucking	50		5		40	
Water shipping	50		5		40	
Electric utility	15	25	14	20	12	20
Gas utility	50		0		0	
Wholesale trade	50		5		40	
Retail trade	50		35		40	
Real estate	50		35		40	
Hotels	90		35		40	
Restaurants	90		65		70	
Health services	90		65		70	
Government enterprise	90		65		70	
Households	50		35		35	
Federal government	90		65		70	
State and local government	90		65		70	

Table 5.--Assumed combustion efficiency and energy content by fuel

Fuel	Unit	Combustion efficiency	Btu content as purchased	Useable burner output
		(Percent)	- -(Million Btu's per unit)- -	
Coal	Ton	0.7800	25.1300	19.6014
Fuel oil	Thousand gallons	.8000	140.0000	112.0000
Natural gas	Million cubic feet	.8000	1,000.0000	800.0000
Wood pellets	Green ton input	.7800	8.6486	6.7459
Wood chips	Green ton input	.6500	9.4000	6.1100
Roundwood	Green ton input	.4500	9.0000	4.0500

Table 6.--Assumed wood fuel preferences by sector group

(In percent)

Wood fuel	Sector group				
	Housing	Commercial	Industrial	Transport	Utility
Wood pellets	0.2500	0.7500	0.2500	0.7500	0.2500
Wood chips	.0000	.2500	.7500	.2500	.7500
Roundwood	.7500	.0000	.0000	.0000	.0000

Table 7.--Calculated wood requirements per unit of fossil fuel by sector group

(In green tons of wood per fossil fuel unit)

Fossil fuel	Sector group				
	Housing	Commercial	Industrial	Transport	Utility
Coal	4.3563	2.9813	3.1325	2.9813	3.1325
Fuel oil	24.8914	17.0346	17.8986	17.0346	17.8986
Natural gas	177.7958	121.6760	127.8473	121.6760	127.8473

Table 8.--Calculated comparable fuel costs per million Btu's

(In dollars per million Btu's)

Fuel	Sector group				
	Housing	Commercial	Industrial	Transport	Utility
Coal	3.8590	1.2231	1.2231	1.2231	0.8905
Fuel oil	3.9946	3.6719	3.4464	4.1116	3.2865
Natural gas	2.6730	2.1486	1.4079	1.5495	1.3683
Wood pellets	2.8045	2.8045	2.8045	2.8045	2.8045
Wood chips	1.3638	1.3638	1.3638	1.3638	1.3638
Roundwood	2.0576	2.0576	2.0576	2.0576	2.0576

Table 9.--Calculated wood cost to replace a unit of fossil fuel by sector group

(In dollars of wood per unit of fossil fuel)

Fossil fuel	Sector group				
	Housing	Commercial	Industrial	Transport	Utility
Coal	0.5712	1.8140	1.2794	1.8140	1.7572
Fuel oil	.5518	.6042	.4540	.5396	.4761
Natural gas	.8247	1.0326	1.1115	1.4318	1.1437

Table 10.--Scenario 1: calculated green wood requirements by fossil fuel and sector

(In green tons)

Sector	Green tons of wood to replace: Coal	Fuel oil	Natural gas	Total
Iron mining	87,609	48,830	211,970	348,409
Highway construction	0	5,133	45	5,179
Well drilling	0	26,885	0	26,885
Maintenance	131	6,262	363	6,756
Meat products	2,417	5,080	8,899	16,396
Milk products	2,613	10,825	5,494	18,932
Frozen fruit and vegetables	0	11,442	13,213	24,655
Logging and sawmill	44,739	25,731	1,226	71,695
Pulp and paper	507,280	500,501	52,056	1,059,838
Chemicals 1	3,789	0	0	3,789
Chemicals 2	588	0	0	588
Chemicals 3	1,241	0	0	1,241
Petroleum refining	6,827	0	0	6,827
Asphalt and pavement	2,352	0	3,587	5,939
Miscellaneous stone	1,797	3,482	23,792	29,071
Blast furnaces	0	0	6,674	6,674
Railroads	0	12,333	8,677	21,010
Trucking	0	2,475	236	2,710
Water shipping	124	2,170	432	2,726
Electric utility	462,812	91,018	74,676	628,506
Gas utility	0	0	0	0
Wholesale trade	373	6,913	3,539	10,826
Retail trade	1,554	54,351	20,415	76,321
Real estate	0	32,504	9,429	41,932
Hotels	0	9,873	6,343	16,215
Restaurants	0	971	4,247	5,219
Health services	4,701	39,740	15,460	59,900
Government enterprise	78,903	33,790	48,411	161,104
Households	12,008	764,961	411,365	1,188,333
Federal government	10,968	67,822	10,108	88,898
State and local government	14,661	163,321	172,289	350,272
Total	1,247,487	1,926,413	1,112,947	4,286,847

Table 11.--Scenario 1: calculated wood cost by fossil fuel and sector

(In thousand dollars)

Sector	Wood costs to replace: Coal	Fuel oil	Natural gas	Total
Iron mining	858	478	2,076	3,412
Highway construction	0	50	0	51
Well drilling	0	263	0	263
Maintenance	1	61	4	66
Meat products	24	50	87	161
Milk products	26	106	54	185
Frozen fruit and vegetables	0	112	129	241
Logging and sawmill	438	252	12	702
Pulp and paper	4,967	4,901	510	10,378
Chemicals 1	37	0	0	37
Chemicals 2	6	0	0	6
Chemicals 3	12	0	0	12
Petroleum refining	67	0	0	67
Asphalt and pavement	23	0	35	58
Miscellaneous stone	18	34	233	285
Blast furnaces	0	0	65	65
Railroads	0	180	127	306
Trucking	0	36	3	40
Water shipping	2	32	6	40
Electric utility	4,532	891	731	6,154
Gas utility	0	0	0	0
Wholesale trade	5	101	52	158
Retail trade	23	793	298	1,113
Real estate	0	474	138	612
Hotels	0	144	93	237
Restaurants	0	14	62	76
Health services	69	580	226	874
Government enterprise	1,151	493	706	2,350
Households	119	7,587	4,080	11,786
Federal government	160	989	147	1,297
State and local government	214	2,382	2,513	5,109
Total	12,750	21,004	12,386	46,140

Table 12.--Scenario 1: calculated fossil fuel balance by fossil fuel and sector

(In thousand dollars)

Sector	Fossil fuel balance			
	Coal	Fuel oil	Natural gas	Total
Iron mining	3,800	20,008	16,807	40,614
Highway construction	0	2,103	1	2,104
Well drilling	0	11,016	0	11,016
Maintenance	1	2,566	5	2,572
Meat products	19	203	118	340
Milk products	20	434	73	526
Frozen fruit and vegetables	0	458	175	633
Logging and sawmill	86	4,994	16	5,096
Pulp and paper	971	2,698	4,127	7,796
Chemicals 1	87	701	323	1,111
Chemicals 2	14	1,110	1,392	2,516
Chemicals 3	29	873	65	967
Petroleum refining	157	22,187	2,053	24,397
Asphalt and pavement	54	3,778	47	3,879
Miscellaneous stone	41	676	314	1,032
Blast furnaces	1,860	541	529	2,930
Railroads	0	6,335	133	6,467
Trucking	0	1,271	4	1,275
Water shipping	1	1,114	7	1,122
Electric utility	14,614	11,498	4,689	30,801
Gas utility	0	67	21,819	21,886
Wholesale trade	3	3,171	75	3,249
Retail trade	13	2,437	433	2,882
Real estate	0	1,457	200	1,657
Hotels	0	443	134	577
Restaurants	0	44	90	134
Health services	4	517	94	614
Government enterprise	71	439	293	803
Households	209	25,535	9,188	34,932
Federal government	10	882	61	953
State and local government	13	2,123	1,043	3,179
Total	22,073	131,679	64,306	218,058

Table 13.--Scenario 1: calculated fuel cost savings or (loss) by fossil fuel and sector

(In thousand dollars)

Sector	Fuel cost savings or (loss)			
	Coal	Fuel oil	Natural gas	Total
Iron mining	(187)	575	(208)	179
Highway construction	0	60	(0)	60
Well drilling	0	317	0	317
Maintenance	(0)	74	(0)	73
Meat products	(5)	60	(9)	46
Milk products	(6)	127	(5)	116
Frozen fruit and vegetables	0	135	(13)	122
Logging and sawmill	(96)	303	(1)	206
Pulp and paper	(1,085)	5,893	(51)	4,757
Chemicals 1	(8)	0	0	(8)
Chemicals 2	(1)	0	0	(1)
Chemicals 3	(3)	0	0	(3)
Petroleum refining	(15)	0	0	(15)
Asphalt and pavement	(5)	0	(4)	(9)
Miscellaneous stone	(4)	41	(23)	14
Blast furnaces	0	0	(7)	(7)
Railroads	0	153	(38)	115
Trucking	0	31	(1)	30
Water shipping	(1)	27	(2)	24
Electric utility	(1,953)	981	(92)	(1,064)
Gas utility	0	0	0	0
Wholesale trade	(2)	66	(2)	62
Retail trade	(10)	519	(9)	500
Real estate	0	311	(4)	306
Hotels	0	94	(3)	91
Restaurants	0	9	(2)	7
Health services	(31)	380	(7)	342
Government enterprise	(516)	323	(22)	(216)
Households	89	6,162	867	7,119
Federal government	(72)	648	(5)	572
State and local government	(96)	1,561	(79)	1,385
Total	(4,006)	18,849	280	15,123

Table 14.--Scenario 2: calculated green wood requirements by fossil fuel and sector

(In green tons)

Sector	Green tons of wood to replace: Coal	Fuel oil	Natural gas	Total
Iron mining	146,014	48,830	211,970	406,815
Highway construction	0	5,133	45	5,179
Well drilling	0	26,885	0	26,885
Maintenance	131	6,262	363	6,756
Meat products	2,417	5,080	8,899	16,396
Milk products	2,613	10,825	5,494	18,932
Frozen fruit and vegetables	0	11,442	13,213	24,655
Logging and sawmill	44,739	25,731	1,226	71,695
Pulp and paper	507,280	500,501	52,056	1,059,838
Chemicals 1	3,789	0	0	3,789
Chemicals 2	588	0	0	588
Chemicals 3	1,241	0	0	1,241
Petroleum refining	6,827	0	0	6,827
Asphalt and pavement	2,352	0	3,587	5,939
Miscellaneous stone	1,797	3,482	23,792	29,071
Blast furnaces	0	0	6,674	6,674
Railroads	0	12,333	8,677	21,010
Trucking	0	2,475	236	2,710
Water shipping	124	2,170	432	2,726
Electric utility	771,353	130,026	124,460	1,025,839
Gas utility	0	0	0	0
Wholesale trade	373	6,913	3,539	10,826
Retail trade	1,554	54,351	20,415	76,321
Real estate	0	32,504	9,429	41,932
Hotels	0	9,873	6,343	16,215
Restaurants	0	971	4,247	5,219
Health services	4,701	39,740	15,460	59,900
Government enterprise	78,903	33,790	48,411	161,104
Households	12,008	764,961	411,365	1,188,333
Federal government	10,968	67,822	10,108	88,898
State and local government	14,661	163,321	172,289	350,272
Total	1,614,434	1,965,421	1,162,731	4,742,585

Table 15.--Scenario 2: calculated wood cost by fossil fuel and sector

(In thousand dollars)

Sector	Wood costs to replace: Coal	Fuel oil	Natural gas	Total
Iron mining	1,430	478	2,076	3,983
Highway construction	0	50	0	51
Well drilling	0	263	0	263
Maintenance	1	61	4	66
Meat products	24	50	87	161
Milk products	26	106	54	185
Frozen fruit and vegetables	0	112	129	241
Logging and sawmill	438	252	12	702
Pulp and paper	4,967	4,901	510	10,378
Chemicals 1	37	0	0	37
Chemicals 2	6	0	0	6
Chemicals 3	12	0	0	12
Petroleum refining	67	0	0	67
Asphalt and pavement	23	0	35	58
Miscellaneous stone	18	34	233	285
Blast furnaces	0	0	65	65
Railroads	0	180	127	306
Trucking	0	36	3	40
Water shipping	2	32	6	40
Electric utility	7,553	1,273	1,219	10,045
Gas utility	0	0	0	0
Wholesale trade	5	101	52	158
Retail trade	23	793	298	1,113
Real estate	0	474	138	612
Hotels	0	144	93	237
Restaurants	0	14	62	76
Health services	69	580	226	874
Government enterprise	1,151	493	706	2,350
Households	119	7,587	4,080	11,786
Federal government	160	989	147	1,297
State and local government	214	2,382	2,513	5,109
Total	16,343	21,386	12,874	50,603

Table 16.--Scenario 2: calculated fossil fuel balance by fossil fuel and sector

(In thousand dollars)

Sector	Fossil fuel balance			
	Coal	Fuel oil	Natural gas	Total
Iron mining	3,353	20,008	16,807	40,167
Highway construction	0	2,103	1	2,104
Well drilling	0	11,016	0	11,016
Maintenance	1	2,566	5	2,572
Meat products	19	203	118	340
Milk products	20	434	73	526
Frozen fruit and vegetables	0	458	175	633
Logging and sawmill	86	4,994	16	5,096
Pulp and paper	971	2,698	4,127	7,796
Chemicals 1	87	701	323	1,111
Chemicals 2	14	1,110	1,392	2,516
Chemicals 3	29	873	65	967
Petroleum refining	157	22,187	2,053	24,397
Asphalt and pavement	54	3,778	47	3,879
Miscellaneous stone	41	676	314	1,032
Blast furnaces	1,860	541	529	2,930
Railroads	0	6,335	133	6,467
Trucking	0	1,271	4	1,275
Water shipping	1	1,114	7	1,122
Electric utility	12,895	10,696	4,262	27,853
Gas utility	0	67	21,819	21,886
Wholesale trade	3	3,171	75	3,249
Retail trade	13	2,437	433	2,882
Real estate	0	1,457	200	1,657
Hotels	0	443	134	577
Restaurants	0	44	90	134
Health services	4	517	94	614
Government enterprise	71	439	293	803
Households	209	25,535	9,188	34,932
Federal government	10	882	61	953
State and local government	13	2,123	1,043	3,179
Total	19,907	130,877	63,880	214,663

Table 17.--Scenario 2: calculated fuel cost savings or (loss) by fossil fuel and sector

(In thousand dollars)

Sector	Fuel cost savings or (loss)			
	Coal	Fuel oil	Natural gas	Total
Iron mining	(312)	575	(208)	55
Highway construction	0	60	(0)	60
Well drilling	0	317	0	317
Maintenance	(0)	74	(0)	73
Meat products	(5)	60	(9)	46
Milk products	(6)	127	(5)	116
Frozen fruit and vegetables	0	135	(13)	122
Logging and sawmill	(96)	303	(1)	206
Pulp and paper	(1,085)	5,893	(51)	4,757
Chemicals 1	(8)	0	0	(8)
Chemicals 2	(1)	0	0	(1)
Chemicals 3	(3)	0	0	(3)
Petroleum refining	(15)	0	0	(15)
Asphalt and pavement	(5)	0	(4)	(9)
Miscellaneous stone	(4)	41	(23)	14
Blast furnaces	0	0	(7)	(7)
Railroads	0	153	(38)	115
Trucking	0	31	(1)	30
Water shipping	(1)	27	(2)	24
Electric utility	(3,255)	1,401	(153)	(2,007)
Gas utility	0	0	0	0
Wholesale trade	(2)	66	(2)	62
Retail trade	(10)	519	(9)	500
Real estate	0	311	(4)	306
Hotels	0	94	(3)	91
Restaurants	0	9	(2)	7
Health services	(31)	380	(7)	342
Government enterprise	(516)	323	(22)	(216)
Households	89	6,162	867	7,119
Federal government	(72)	648	(5)	572
State and local government	(96)	1,561	(79)	1,385
Total	(5,433)	19,269	218	14,055

ECONOMIC IMPACT OF SUBSTITUTING LOCAL WOOD ENERGY FOR IMPORTED FOSSIL FUELS

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This report summarizes our research to estimate the regional economic impact of using more wood fuels in place of some fossil fuels in northeastern Minnesota. The effect of such import substitutions is a common question facing economic development agencies. Our primary tools were an input-output model of the region plus an economic projection system called SIMLAB. Beginning with a base-line economic structure for the region in 1980, we made three projections of economic growth to the year 2000. The first projection portrays the region's economic structure in 2000 if fossil fuels were the almost exclusive source of energy. Two other projections portray the economy if two different scenarios of fossil to wood fuel conversions were achieved. Although the advantages of using locally produced wood in place of an expensive import would seem clear, some are not so obvious. In particular, if an import substitution can save money, the region's exports also become more competitive, in effect, a double-barreled advantage.

BACKGROUND

The study area, known collectively as the Arrowhead, consists of seven counties in northeastern Minnesota: Aitkin, Carlton, Cook, Itasca, Koochiching, Lake, and St. Louis. The Arrowhead region depends on four sectors: taconite mining, timber, tourism, and transportation. Although the Arrowhead uses much fossil fuel, it produces none; and it began to experience economic hardship during the OPEC oil crisis.

The region's economy may have begun to decline with the OPEC crisis, but accelerated when several taconite mines cut production or closed. As local authorities sought new sources of economic growth, it was not surprising that the Arrowhead's forests were seen as a likely base for development.

TWO ECONOMIC DEVELOPMENT STRATEGIES: EXPORT BASE ENHANCEMENT AND IMPORT SUBSTITUTION

There are two major ways to change a region's economic structure: export base enhancement and import substitution. Finding new ways to use taconite, such as the direct reduction of ore in the Arrowhead, or encouraging new investments in its pulp and paper industry, represent approaches to enhance the export base. Using wood instead of imported fossil fuels represents an import substitution approach. These two approaches are not mutually exclusive.

A region's prospects depend on its exports. Those exports bring in monies from outside the region, which in turn pay for any imports and for goods and services produced locally supporting its *export base*. Exports

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have a "multiplier effect", creating income that can be used to buy goods and services from local as well as export servicing industries. Money earned from exports is spent for several purposes such as savings and purchasing imported or local goods and services.

But savings and imports represent leakages from the region's income stream, and therefore, reduced multipliers. On the other hand, the more money spent locally, the greater the multiplier effect; thus, the advantage of *import substitution.*

This does not mean, however, that a region should always be self-sufficient. If a cheap import is replaced by a more expensive good produced locally, then import substitution increases the costs of its exports. And as a result the region's competitive position in the rest of the world declines.

There are two positive multiplier effects if a region can substitute cheaper, locally produced goods and services for those previously imported. First, new local production creates jobs and income. Second, the region's export multiplier increases. After a "good" import substitution is found, a region's export base becomes even more significant than it was before the import substitution. These two effects actually represent two facets of the same affect: increasing the ratio of local activity to export activity. This report projects the economic impacts of import substitution and the resulting export base enhancement in the Arrowhead.

Input-Output Models

An input-output model is a general equilibrium interindustry model originally developed by Wassily Leontief to guide national economic planning. Input-output systems are popular for both national and regional analysis especially because recent computer improvements make the process more affordable.

An input-output system consists of three basic tables. The first, the Transactions Table, traces interindustry sales and purchases within a defined region as well as by industry exports and imports to and from the "rest of the world". Developing this table is the heart as well as major expense of an input-output study. The second table, the Direct Requirements Table, shows for each industry, the proportion of purchases from every other industry required to produce one dollar of its output. It is easily calculated once the first table is complete. The third and most useful table shows the Total of Direct and Indirect Requirements and is so termed. This table is conceptually simple to calculate once the second table is complete.

This third table, also called the Leontief Inverse, allows us to determine the gross output for any regional industry, assuming any level of final demand for the same industry and assuming no technological change. In other words, projected changes in final demand for any one industry can be translated into changes in gross output for all industries in the region.

A key facet of input-output analysis is the use of interindustry earnings and employment multipliers that also form a key part of SIMLAB. These multipliers are derived from column totals in this third table.

SIMLAB Projection System

In contrast, SIMLAB is a system for simulating a region's economic growth and is based on an initial input-output model of a region's economy plus a set of parameters describing fundamental economic inter-relations and how they might change in the future. SIMLAB was developed at the University of Minnesota by Wilbur Maki and others. SIMLAB can be used to update an out-of-date input-output model to the present or to project an economy into the future.

Although an actual input-output study of the study region would be best, the expense of such efforts dictates that they can only be undertaken at wide intervals. And in fact, the input model of the Arrowhead is based on secondary data. Yet, many industries as well as public agencies often need to develop intermediate projections. These are very useful for developing strategies to enhance economic growth. Thus, the need for SIMLAB.

A SIMLAB model consists of several interrelated modules: outputs of one module are inputs for the next.

Many of the parameters assumed in the following modules can be changed and, as a result, many future economies can be projected. However, the following applications assume only one parameter set, which is held constant throughout. This set is regarded as fairly conservative and should not confound the wood energy projections with other factors expected to affect future economic structure.

* THE INVESTMENT MODULE estimates the region's capital requirements implied by each sectors' gross output in the input-output model. These estimates are in turn based on each sectors' need for new production equipment, pollution abatement, and repair and maintenance. Total investment for any sector is limited by its historical business income and retained earnings pattern.

* THE DEMAND MODULE estimates final demand for each sector based on previous estimates of the investment module, personal consumption expenditures from the population module, and government expenditures from the government module.

* THE MARKET MODULE estimates each sector's regional export to the "rest-of-the world" based on key

assumptions about national economic growth and regional market share. This module follows the export base notion of regional economic growth.

* THE GOVERNMENT MODULE estimates federal, state, and local government employment from estimated rates of employment change for the region. Government employment is also linked to regional population levels and economic activity.

* THE PRODUCTION MODULE takes the required regional output as given by the previous modules and feeds it to the Leontief Inverse of the region's input-output model. The result of this model is then compared to the output level possible with the amount of capital in the region plus new capital from the investment process. If the capital-constrained regional output is lower than the initial estimate of regional output by the demand module, the lower of the two values is assumed.

* THE EMPLOYMENT MODULE estimates employment and unemployment by occupation implied by the previous modules and based on each sector's assumed output per hour and average hours worked per week. These employment estimates then lead to in-or-out commuting in the short run and, in the following population module, to in-or-out migration in the longer run.

* THE POPULATION MODULE estimates the new regional population implied by gross output for each sector. These new population estimates are based on a starting population, birth and death rates, and estimated employment from the previous module.

* THE PRIMARY INPUT MODULE estimates the new regional earnings implied by the gross output of each sector. Earnings include employee salary and wages, business after-tax income, proprietor income, unemployment compensation, and transfer payments.

* THE HOUSEHOLD MODULE estimates housing requirements implied by the population calculated in the population module. Housing demand includes owner-occupied and rentals, and is measured using Census Bureau crowding and plumbing quality criteria.

Import Substitution and Input/Output-SIMLAB Interaction

We used the input-output model of the Arrowhead economy and SIMLAB in an iterative fashion to examine the impacts of import substitutions as well as future economic growth to the year 2000.

Step 1

The original 1977 input-output model was updated to 1980 because a local oil refinery had ceased operation by 1980. This update required us to construct a new transactions table to account for the expanded import of fossil fuels from 1977 to 1980. We then calculated the new Direct Requirements Table and the Direct and Indirect Requirements Table, the so-called Leontief Inverse. The resultant input-output model shows the Arrowhead's economy in 1980, depending heavily on imported fossil fuels.

Step 2

We next turned this 1980 economy over to the SIMLAB model, which projected the region's economic growth to the year 2000. As described above, this projection is based on a host of assumptions contained in the SIMLAB modules about such factors as national GNP growth, regional market share, and population growth. This projection is our so-called base line, table 1.

Step 3

We further modified the 1980 input-output model in a fashion similar to step 1 above. But in this case, we substituted locally produced wood fuels in various ways and amounts by various sectors for imported fossil fuels. As before, these changes were made to the transactions table, which was then used to calculate a new Leontief Inverse (the Direct and Indirect Requirements Table).

Two separate wood fuel expansion scenarios were developed for step 3, and therefore two more new Leontief Inverses were calculated. Although we assumed practically all sectors underwent some changes in fuel use patterns, two sectors changed the most: iron mining and electric utilities. Both sectors use much coal to produce electricity; the former for its own use and the latter for public consumption. Scenario A portrays these two sectors converting 15 percent of their coal use to wood. Scenario B portrays their converting 25 percent of their coal to wood.

Achieving these scenarios would reduce annual coal consumption by 28 or 35 percent respectively, oil consumption by 23 or 24 percent, and natural gas consumption by 16 or 17 percent.

Step 4

The two new Leontief Inverses of the Arrowhead economy, which now represent what the region's economy would look like in 1980 with less imported fuels and more wood energy, were also turned over to SIMLAB.

Under the same set of previous assumptions about future economic growth, SIMLAB then projected the Arrowhead's economy to the year 2000 for both scenario A and B.

Table 1.--Leontief output multipliers

Sector numbers	Industry	Base line	Scenario A	Scenario B
1	Dairy & Poultry Prod.	1.4720	1.4733	1.4738
2	Meat An. & Prod.	1.3667	1.3679	1.3684
3	Food, Feed Gr.	1.3208	1.3218	1.3220
4	Other Crops	1.3646	1.3658	1.3660
5	Forest., Fish, Prod.	1.1731	1.1734	1.1735
6	Agr., For., Fish. Serv	1.3422	1.3436	1.3441
7	Iron & Ferr. Ores	1.4247	1.4355	1.4385
8	Nonferrous ores	1.2162	1.2191	1.2205
9	Coal & Peat Mining	1.2179	1.2200	1.2209
10	Stone, Clay Mfg., Qua	1.2388	1.2414	1.2425
11	Other Mining	1.0000	1.0000	1.0000
12	New Construction	1.3639	1.3662	1.3663
13	Main. & Rep. Constr.	1.2698	1.2718	1.2719
14	Ordnance	1.0000	1.0000	1.0000
15	Meat products	1.4770	1.4795	1.4798
16	Dairy products	1.4667	1.4713	1.4717
17	Canned, Froz. Pres.	1.3581	1.3637	1.3642
18	Grain Mill. Prod.	1.4282	1.4291	1.4294
19	Bakery Prod.	1.2170	1.2180	1.2183
20	Alch. Bev., Soft Dr.	1.2217	1.2227	1.2229
21	Misc. Food, Tob.	1.2120	1.2131	1.2134
22	Textile Goods	1.2751	1.2767	1.2772
23	Apparel, Fab. Tex.	1.3022	1.3031	1.3035
24	Logging	1.2342	1.2511	1.2512
25	Sawmills	1.6710	1.6789	1.6494
26	Particleboard	1.4208	1.4247	1.4262
27	Other Wood Prod.	1.5648	1.5687	1.5694
28	Furniture	1.4340	1.4358	1.4362
29	Pulp & Paper Prod.	1.3971	1.4396	1.4407
30	Paperboard Cont.	1.2236	1.2265	1.2269
31	Printing & Publ.	1.5011	1.5074	1.5078
32	Chem. & Allied Prod.	1.3735	1.3779	1.3789
33	Petr. Ref. & Prod.	1.0919	1.0935	1.0938
34	Rubber Prod.	1.2376	1.2392	1.2398
35	Leather Prod.	1.2326	1.2335	1.2337
36	Glass, Stone, Clay	1.3304	1.3400	1.3408
37	Primary Fe/Steels	1.4429	1.4491	1.4503
38	Iron & Steel Found.	1.4354	1.4381	1.4390
39	Primary Copper	1.2745	1.2760	1.2765
40	Other Prim. Met.	1.4140	1.4170	1.4183
41	Fabricated Metals	1.3300	1.3316	1.3321
42	Farm Machinery	1.3113	1.3123	1.3126
43	Machine Shops	1.2611	1.2625	1.2630
44	Other Non. Electr.	1.3208	1.3219	1.3223
45	Comp. Off. Mach.	1.0000	1.0000	1.0000
46	Serv. Ind. Mach.	1.2549	1.2559	1.2562
47	Electrical Mach.	1.2462	1.2474	1.2478
48	Motor Vehicles	1.3163	1.3173	1.3175
49	Other Trans. Equip.	1.3210	1.3223	1.3227
50	Prof., Scient.	1.3620	1.3637	1.3641
51	Optical, Ophth., Pho	1.2641	1.2655	1.2658
52	Misc. Mfg.	1.3490	1.3507	1.3512
53	Railroad Trans.	1.3123	1.3177	1.3183
54	Local Transit	1.2027	1.2043	1.2047
55	Truck Trans.	1.1972	1.2002	1.2003
56	Air Trans.	1.1708	1.1716	1.1718
57	Other Trans.	1.4574	1.4644	1.4649
58	Communications	1.1590	1.1599	1.1602
59	Electric Utilities	1.2860	1.3579	1.4031
60	Gas Utilities	1.4532	1.4546	1.4547
61	Water & San. Serv.	1.2837	1.2879	1.2883
62	Wholesale Trade	1.1996	1.2020	1.2023
63	Retail Trade	1.1732	1.1810	1.1819
64	Finance, Ins.	1.3662	1.3677	1.3683
65	Real Estate	1.1705	1.1737	1.1739
66	Hotels, Pers., Rep.	1.2907	1.2991	1.3001
67	Business Serv.	1.2463	1.2471	1.2473
68	Eat. & Drink. Places	1.4456	1.4488	1.4495
69	Automobile Repair	1.2152	1.2162	1.2164
70	Motion Pic. & Recr.	1.3283	1.3296	1.3301
71	Health Services	1.2372	1.2454	1.2459
72	Educ., Nonpr.	1.3088	1.3117	1.3128
73	Fed. Gov't. Enter.	1.1291	1.1307	1.1313
74	State & Local Entr.	1.4822	1.5961	1.6005
75	Miscellaneous	1.4696	1.4710	1.4712

Table 2.--Wood energy development effects on employment, intermediate sales, and gross output

	Absolute and percentage changes from new wood energy sector in the year 2000			
	Scenario A		Scenario B	
	Million dollars	Percent change	Million dollars	Percent change
Employment				
Wood energy sector	332.0	101.3	352.0	110.6
Regional total-all sectors	2,500.0	2.7	2,752.0	2.9
Intermediate sales				
Wood energy sector	23.7	148.5	28.5	178.8
Regional total-all sectors	59.3	5.5	67.3	6.2
Gross output				
Wood energy sector	53.1	101.2	58.0	110.5
Regional total-all sectors	133.6	2.9	145.7	3.2

RESULTS

Differences between the base-line projection and the two import substitution scenarios, all for the year 2000, are shown in table 2. Differences are due entirely to the estimated changes in the region's transaction table because a significant portion of fossil fuel was replaced with wood. All values are in 1977 dollars.

As we would expect, substituting wood for fossil fuels has major impacts on employment, intermediate sales, and gross output in the region (table 2). The following comparisons are best examined from two perspectives: the effects on the region as a whole versus on the wood energy sector itself.

Impacts to the Region as a Whole

Between 2,500 and 2,750 new jobs would be created, about a 3-percent rise in employment. This increase reflects changes in both full- and part-time employees, because this kind of wood industry usually employs many part-time workers.

So too, this kind of wood industry is characterized by a very low capacity utilization. That is, if allowed to produce more, sectors could expand their output rapidly without increasing the number of direct jobs. The same number of workers would simply work more hours.

Intermediate sales in the region would increase $60 or $67 million, a 5.5 or 6.2 percent increase. This relative increase is larger than the employment increase primarily due to the capacity utilization concept just mentioned; although the number of new workers wouldn't be as large, fuel consumption, new equipment, and added transport etc. would all jump dramatically.

The value of gross output would increase $134 or $146 million, again about a 3-percent increase. The relative increase is not as large as intermediate sales because although intermediate sales would rise at the expense of imported fossil fuels, total economic output in most other respects would be substantially the same. That is, the increased output due to an expanded wood energy sector is simply spread over a larger total.

Impacts to the Wood Energy Sector

What is interesting here are the differences between the 15 percent and 25 percent coal to wood conversions. Differences between these and the base line are not quite as large as they appear, for although the starting point was low it was not really zero. Also we would expect a large jump.

Although employment and gross output differences between scenarios were both 9.3 percent (110.6 minus

101.3 and 110.5 minus 101.2), intermediate sales differed by 30.5 percent (178.8 minus 148.5). The 10-percent difference in coal to wood conversions by the iron mining and electric utility sectors has a fairly small employment effect compared to its effect on intermediate sales for the same reasons used to explain the differing impacts to the region as a whole.

In other words, although the development of a wood energy sector to displace imported fossil fuels would have a good impact on the region, the effect on jobs would not be as large as we might first expect.

Several final points need emphasis. Other portions of the research effort estimated the amount of wood available for energy and conventional purposes. These projections do not account for possible job losses in other wood products sectors due to a lack of wood. Nor do they deal with possible wood price changes resulting from increased wood use. Increased wood prices might make import substitution less efficient, even undesirable. But such an effect is doubtful, considering the surplus forest resource.

In input-output analysis, there are procedures for introducing local households into the industrial matrix which are termed, "...closing the table with respect to households." When such a procedure is carried out, the multipliers in the Leontief Inverse include an induced effect from household consumption.

Although no such procedure was used here, a type of induced effect does appear in the SIMLAB Demand Module. Household income was calculated as a function of the region's gross output. Income elasticities of demand were then applied to calculate household consumption from each of the 75 industries. This consumption then induces further output and employment for the region in addition to those coming out of the industrial component. Thus, stated employment impacts were larger than other models of a more static nature.

POLICY OPTIONS TO ENCOURAGE WOOD ENERGY USE IN NORTHERN MINNESOTA

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Wood is extremely important to the economy of Minnesota. The State's 13.6 million acres of commercial timberland are the source of wood fiber that is the prime raw material for more than 1,400 wood processing facilities. Minnesota's wood-based industry ranks among the State's three leading industries, employs more than 50,000 persons, and produces nearly $3 billion in product value.

The potential of wood residues has only recently been explored. Wood residues exist in many forms; trees and tree remnants after logging such as uncut stems remaining on the harvest site, and branches and tops, entire stands of low quality or dead trees, wood manufacturing waste, and urban wood waste from construction sites, or trees from lawns and boulevards. While these residues can be used in many ways, using them for energy has received particular attention. For many years, inexpensive fossil fuels discouraged the use of wood for energy, but as fossil fuel prices escalated rapidly during the 1970's, wood and wood residues were burned more frequently. Wood energy could supply between 8 and 15 percent of the Nation's future energy needs, a magnitude of considerable importance to a Nation attempting to reduce its dependence on foreign oil supplies (General Accounting Office 1981).

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BARRIERS TO WOOD-RESIDUE UTILIZATION

There are many complex obstacles to using more wood residues. Ironically, removing one deterrent may well lead to unexpected positive or negative consequences elsewhere in the technical and economic systems that determine wood residue use. Thus, policies must be carefully devised to enhance wood residue use without detracting from other forest uses. What follows is a general review of five major conditions influencing residue use. It is by no means complete, yet it provides an appreciation of factors that must be considered when new wood-residue policies are proposed (Wheatcraft *et al.* 1984).

Technical Barriers

Some technical barriers prohibiting expansion of wood residues for fuel can be linked to the lack of efficient harvesting equipment—especially small-scale equipment. An extensive amount of research has focused on improving harvesting technology in past decades, but the resulting equipment generally operates most efficiently on a large scale. A typical whole-tree chipping system, for example, costs nearly $1 million. Such costs can be prohibitive for small-scale loggers. Additional research is needed to develop equipment that will operate economically on a small scale. Ad-

vances in wood-burning technology have eliminated low efficiency and smoke as barriers to the use of wood residue as a fuel. Research funded by government agencies and tested and implemented by wood-based and related enterprises illustrate the effectiveness of government and private sector cooperation in dealing with technology of this sort. Wood storage and handling however, is an area that could benefit from additional research. Wood fuel is costly to handle because of its bulk and size variability and any savings from burning wood as a fuel may quickly be consumed by the added cost of storage and handling. Without additional research on such problems, the use of wood fuels may be hindered. Lack of high quality and reliable forest road systems often limit access to forests and thus make some wood residues uneconomical to harvest. Access problems are widespread deterrents to harvesting wood residue on both public and private forests.

Economic and Financial Deterrents

Depressed economic conditions experienced Nationwide during the past 2 to 3 years may be the single-most important factor impeding the development of wood energy. These conditions have curtailed demand for the products manufactured by wood-based enterprises and, consequently, have limited the need for energy required in manufacturing. High interest rates and high equipment costs also discouraged the purchase of residue harvesting and processing equipment.

Lack of venture capital also deterred wood energy development. Financial institutions are reluctant to extend credit to new and unproven businesses such as wood pelletizers, wood distributors, and wood energy harvesters. They may either refuse financial support entirely or charge a premium interest rate to cover the high risk. Although some capital is available through government agencies (e.g., Small Business Administration loans, Department of Energy grants), total investment capital at investment-inducing interest rates remains a problem.

Limited funding for wood residue research, marketing, and informational programs have also deterred wood energy development. Although federal agencies have invested heavily in research and demonstration projects during the past decade, current investments have been insufficient to make the technical breakthroughs necessary for more widespread use of forest residues.

Institutional and Administrative Conditions

Many institutional and administrative conditions impede the greater use of wood-residues. However, such barriers can often be overcome with minor changes in agency rules and regulations. Consider the following:

- Loggers and operators are discouraged from removing low grade or unmerchantable materials, i.e., wood residues, because of the public stumpage pricing procedures that lead to excessive stumpage prices.
- Public timber appraisal procedures establish minimum merchantability standards but do not consider economic and environmental benefits that may acrue if more usable wood (i.e., residues) were removed (General Accounting Office 1973).
- Public timber-harvesting administrators fail to enforce sale contract provisions that call for removing not only high value material, but also all wood material (including residues) as specified in the contract.
- Limited coordination among public agencies prevents establishing an action agenda to develop wood energy markets and encourage programs that logically flow therefrom. Due to the lack of coordinated and comprehensive regional plans for managing and using wood residue, no long-range outline can be focused on opportunities for utilizing such material.
- Wood residue users have limited assurance of reliable wood residue supplies at stable prices. Such conditions detract from investments in wood residue harvesting and burning equipment. Public and private forest landowners may be reluctant to make long-term contracts for a variety of reasons (e.g., others might construe this as an attempt to reduce competition, they fear that they would be unable to take advantage of rising future prices for wood and legal restrictions).
- Nonindustrial private forest landowners own 40 percent of Minnesota's commercial forest land. These owners control small, fragmented parcels of forest land, frequently espouse nontimber land management objectives, often have limited knowledge of forest management opportunities, and usually face severe financial limits on their ability to manage timberland. This creates difficulties for wood residue users who depend on these small parcels of land.
- Laws restraining prices of energy that compete directly with wood deter optimal flow of potential energy supplies. Regulating natural gas prices at an artificially low level results in consuming gas at the expense of other, really cheap energy sources such as wood residues.

Informational Constraints

Properly targeted and sustained flows of information about the availability of wood resiudes can encourage

their use. A major information barrier is the lack of wood residue price and production costs. Lacking such knowledge makes wood residue investments appear much more risky than they actually are and discourages investment in a viable and often profitable venture. Information voids are especially troublesome to potential investors evaluating new and untried energy sources and processes—such as wood residues. When compared with tried and proven energy technologies such as fossil fuel, wood residues appear riskier. Distributing information about the advantages and disadvantages of wood as an energy source can reduce this illusion of risk.

Adequate means of distributing existing information must be found. A central source for disseminating information to potential wood energy suppliers and users would be helpful. Another way to get information to potential users is to hold educational programs concerning wood residue availability and the best technologies for their harvest and use.

Environmental Concerns

Environmental concerns about increased wood use must be addressed. The more intensive timber management activities necessary to utilize wood residues (e.g., additional roads, removal of biomass) may have adverse effects on natural environments. Some people are also concerned about the uncertain effects of whole-tree utilization on future forest productivity and an increase in the level of air pollutants associated with certain forms of wood-burning equipment. All of these problems are controllable but may require troublesome and costly regulatory procedures.

PROGRAM PROMOTING WOOD USED FOR ENERGY

Federal Initiatives

General Accounting Office

The General Accounting Office (GAO) of the U.S. Congress periodically reviews selected National issues and suggests courses of action. Since 1973, the Office prepared two major reports addressing the use of wood residues. In both, the Office concluded that the Nation would be substantially better off if wood residues were more widely used for energy. The first report was issued in 1973 and recommended that federal land management agencies (i.e., USDA Forest Service, USDI Bureau of Land Management) take the following actions (General Accounting Office 1973):

- Modify federal timber sale procedures to ensure removal of economically usable wood that can be processed by facilities in the vicinity of the sale area.
- Establish methods and procedures for determining the amount of wood to be removed from the sale area so that the economic and environmental benefits from the increased use of wood will be recognized. Consider the feasibility of shipping the material outside the sale area.
- Ascertain the level of utilization possible under the best available timber processing technology.
- Analyze the effect of Federal assistance programs on increasing timber processing capabilities in areas where the timber resource is underutilized.
- Explore ways to increase wood processing capabilities.

In 1981, the General Accounting Office focused on specific opportunities for utilizing wood for energy. In a report entitled "The Nation's Unused Wood Offers Vast Potential Energy and Product Benefits" the Office urged the USDA Forest Service and the Department of Energy to place a higher priority on encouraging the use of wood for energy (General Accounting Office 1981). The report identified many barriers to increased wood fiber utilization that exist at the National level. Overall program recommendations were as follows:

- Conduct a cooperative program to assess areas believed to have the most promise for residue use. The assessments should inventory residue quantity and availability, evaluate potential residue uses, discuss barriers to increased residue uses, and propose ways to increase residue use. The USDA Forest Service should take the lead role in this assessment.
- Develop a National wood residue plan to be presented to Congress within 2 years. The plan should include residue use goals and recommendations for policy actions to overcome any barriers to achieving these goals.
- Continue to develop and demonstrate projects involving residue handling equipment.
- Develop standardized methods for evaluating the costs and benefits of wood fuel use in Federal facilities.
- Establish a program promoting the use of wood fuel. The program may involve demonstration projects, direct technical assistance, or educational materials.

The following recommendations were made specifically to the Secretary of Agriculture:

- Upgrade the forest survey to include an inventory of all potentially usable biomass.
- Request legislation that would authorize the U.S. Department of Agriculture to grant private firms either title or exclusive license to manufacture and

sell wood residue technologies developed by government.

- Adopt a more flexible policy regarding long-term contracts to assure that residues from National Forests will be available continuously.

- Reduce indiscriminate burning of piled material on the landings or as scattered logging slash.

USDA-Forest Service

The Forest Service has attempted to improve timber utilization standards for several decades and has recently been the Department of Agriculture's lead agency in efforts to develop programs to encourage wood residue utilization. In the Pacific Northwest tremendous volumes of wood fiber frequently remain after harvest. In the past, most of this fiber was burned in place—much to the detriment of air quality. The Forest Service instituted regulations in Federal timber harvesting contracts that required such material to be used—consistent with existing technology. Timber harvesters were required to concentrate unmerchantable material on harvested sites to increase its economic attractiveness to potential users. The Forest Service also instituted per acre pricing (lump sum) of small material, hoping that more material would be removed from the harvested site. Although these were positive steps, they placed an inordinate amount of the burden on timber purchasers. Without sufficient residue markets, purchasers were unable to sell the material.

The rapid rise of fossil fuel prices during the early 1970's led the Forest Service to further examine various potentials that wood fiber might have as an alternative fuel source. This examination led to further research in forest engineering, products utilization, economics and marketing. Such efforts resulted in a report entitled "A National Energy Program for Forestry" (USDA Forest Service 1980). Focusing on attaining a forest biomass energy production goal established by the U.S. Department of Agriculture, the Forest Service report defined five areas on which to concentrate:

- Produce current, accurate resource information. Incorporate total biomass measurements into inventory procedures.

- Improve resource supply. Apply improved forest management techniques.

- Develop equipment to recover forest biomass. Encourage improved forest biomass recovery by changing timber sales procedures.

- Improve conservation by substituting wood for other raw materials, increasing light frame construction, increasing management efficiency, weatherizing buildings, and processing wood products efficiently.

- Protect wood products from environmental degradation.

The program placed the Forest Service in a leadership position involving the utilization of wood residues for energy. Such leadership has been exercised through the Agency's biomass energy program implemented by reasearch, cooperative State and private forestry activities, and the National Forest system.

The Forest Service has also played an important role in establishing rules and regulations required by the Wood Residue Utilization Act of 1980. A special wood residue utilization program was established by the Forest Service to carry out the guidelines of the Act. The program has never been adequately funded, however, and will expire with little of its potential realized if the law is not reauthorized after a 5-year period.

U.S. Congress

The U.S. Congress has been active on the wood energy front by enacting several laws to promote specific aspects of wood energy production. Consider federal investment tax credits. Under the Energy Tax Act of 1978, investors receive a 10-percent federal tax credit when investing in wood energy facilities. The amount of the investment eligible for the tax credit depends upon the life of the facility and whether it is new or used. While the tax credit has a limit, excesses can be carried forward or back. Another tax incentive is the rapid amortization of pollution control facilities that can include plants utilizing wood waste or wood residues. And, lastly, the Economic Recovery Tax Act of 1981 increases depreciation rates for equipment used to cogenerate steam and electricity.

Congress also established financial programs to encourage investment in wood energy projects. Because these programs were in effect for only a short period of time, overall program effectiveness is difficult to measure. One such program provided credits for producing densified wood. The program was difficult to administer at the National level and led to capital investments in projects with an inordinately high level of risk and low chance of success. Congress also established financial support programs to convert schools and hospitals to wood energy.

In 1980, Congress sought increased utilization of wood residues by establishing the Wood Residue Utilization Act. The Act authorized the Secretary of Agriculture to conduct a 5-year pilot program to develop, demonstrate, and distribute information on feasible methods to increase and improve wood residue utilization. The program's thrust was to increase and improve wood residue utilization in residences, commercial businesses, industries, and powerplants.

Promoting cogeneration activities is another area where Congressional efforts helped overcome barriers inhibiting wood-energy growth. Cogeneration is affected by several Federal laws including the Public Utilities Regulations Policy Act of 1978 (PURPA), the Power Plant and Industrial Fuel Use Act of 1978 (FUA), and the Natural Gas Policy Act of 1978. The Federal Energy Regulatory Commission also has important cogeneration incentives. Under the Act, electric utilities must purchase electricity from qualifying cogenerators as well as sell electricity to them at nondiscriminatory rates. Interconnections must be established between the cogenerator and the utility's system. The Act also exempts cogenerators from certain regulations under the Federal Power Act and the Public Utility Holding Company Act. Legislative backing for the sale of electricity is important for cogenerators. Since enactment, the utility industry has challenged many of the Act's provisions in court, but most of the law's provisions have been upheld.

U.S. Department of Energy

The U.S. Department of Energy also plays an important role. It has been a leader in developing and funding various demonstration projects that have proven the reliability of wood-produced energy. In addition, the Department has coordinated the funding of resource availability studies and informational programs used to promote the direct combustion of wood. It has also funded research to improve harvesting and delivering forest residues.

State Programs

Several States promote the use of wood residues for producing energy and can serve as models for the State of Minnesota.

North Carolina Wood Energy Program

North Carolina has one of the most active programs for promoting wood energy, based on a coordinated plan to outline reasonable wood energy objectives. The plan was developed by a special task force established by the governor. The task force, known as the Wood Energy Coordinating Group, included members from the State's Department of Natural Resources and Community Development, Department of Administration, Department of Commerce-Energy Division, and the University of North Carolina.

The task force's early efforts included the aggressive pursuit of outside funding for demonstration projects, educational programs, and technical and financial assistance programs. This activity resulted in substantial funding by the U.S. Department of Energy, the U.S. Environmental Protection Agency, the North Carolina Energy Institute, the National Science Foundation, and other organizations.

Specific activities and responsibilities for the Wood Energy Coordinating Group were laid out in a master plan (North Carolina Wood Energy Coordinating Group 1978). These activities and responsibilities included developing markets for wood fuel, developing supply systems for wood fuel, developing research mechanisms, assessing the processes and techniques of using wood fuel, and analyzing the use of wood as a home fuel. Within these areas separate programs were developed for education, demonstration, technical assistance, and research.

The task force operated under the direction of a full-time Wood Energy Project Coordinator. Through the efforts of the task force, the State has encouraged a large number of energy-intensive industries (i.e., brick making and textile plants) to convert to the use of wood as their major energy source.

The North Carolina legislature has also promoted the use of wood for energy. Tax assistance legislation provides a 15-percent increase in depreciation to industrial concerns that convert from a fossil fuel energy system to a wood energy system. This allows more rapid write-off of wood burning equipment.

Along with work done by the wood energy task force, North Carolina has developed a strong extension program to promote wood energy. An extensive slide-tape presentation has been prepared to describe the disadvantages, advantages, supply issues, and other pertinent information for using wood. The program has been an effective tool for promoting wood energy development throughout the State.

North Carolina's success is based on the cooperation of the State's wood energy group and its university extension department. These group efforts have helped to alleviate the information gap concerning wood fuel and wood burning energy systems. The wood energy group's work is published in an annual report that provides an update on wood energy conversions and current research projects. The report provides information to the public and increases the awareness of the current situation concerning the use of wood for producing energy.

Oregon Wood Energy Development Program

The State of Oregon has taken a different approach to promote wood energy use. The State realized that utilizing waste wood or excess wood from timber harvests could significantly reduce pollution problems resulting from current wood residue disposal methods. Switching to wood energy was also perceived as a means to create jobs and reduce future energy demands. With these ideas in mind, Oregon developed a

program of tax incentives and financing programs to encourage investment in equipment to burn wood. Oregon carefully coordinates State programs with Federal programs.

Oregon offers a tax credit to reduce the cost of installing solid waste utilization facilities. This credit can be applied to facilities that convert wood waste into energy or other usable products and can also be used for additions to solid waste handling facilities that increase the production of energy from the plant. The amount of the credit differs with the life of the facility up to a maximum of 50 percent. Oregon also provides a 10-percent tax credit on certified investments in economically lagging areas. To qualify for the credit, investments must exceed $25,000 and the new facilities must have a reasonable expectation of creating new permanent jobs. These requirements can usually be met by larger wood energy conversion facilities. Lastly, investors receive a 1-year bonus of an extra 20-percent write-off on qualifying property. This write-off is in addition to the regular depreciation allowance.

Oregon offers a variety of financing options that may be used by wood energy project investors. These include a substantial reduction in the interest rate charged for borrowed capital used for wood conversion projects. The financing options depend on the sale of industrial development revenue bonds and are available from the State to finance certain business projects, from the counties for financing pollution control facilities, or from the various port districts for development within port areas.

The tax incentive and financing options create a positive investment climate for private firms in Oregon. Investments in producing wood energy are riskier than many other investments. Incentive programs serve to reduce risk and induce companies to make new capital investments. Oregon bears some of this risk and probably encounters a short-term decrease in tax revenues. However, if these programs stimulate significant investment, the State should reap substantial benefits in the long run.

Washington Wood Energy Directives

Although planning for wood energy in Washington has not been as extensive as in North Carolina and Oregon, significant actions have been taken. The latest timber management plan prepared for Washington specifically proposes using wood energy—if wood is the most economical use. This recognition places the use of wood energy on equal footing with other wood fiber uses. Additionally, the 1980 Washington legislature enacted a law requiring the Utilities and Transportation Commission to grant higher rates of return for utilities generating electricity by cogeneration or from renewable resources. The legislature also exempted wood energy production costs from a 3.6 percent Public Utility Tax.

PROGRAM AND POLICY OPTIONS

As we have seen, many program and policy options are available to encourage the use of wood energy. Following is a list—along with appropriate summaries—of major program and policy types that governments might use. An effort is made to describe new program types that could prove effective. Obviously, however, the ultimate combination of policies and programs must be designed with an understanding of the prevailing physical, economic, administrative, and political conditions. The following "laundry list" is presented as a means of displaying alternatives, realizing that many may be infeasible for one or more reasons (Wheatcraft *et al.* 1984).

Timber Harvest and Pricing Policies

Policies and regulations to guide public forest administrators can have a significant effect on wood residues use. Agencies frequently have difficulty in adopting rules and regulations to promote wood used for energy because, unlike private firms, their goals are not linked exclusively to maximizing revenues. Policies developed by public forest managers are constantly scrutinized by a variety of user groups having vastly different ideas of how public forests should be managed. Public agencies must continually balance policies so that a particular group is not unduly favored. In such an environment, administrators must be especially creative and innovative. In the following sections, policy changes in timber harvest regulations and stumpage pricing fees are explored that may encourage increases in forest residue utilization. Strong administrative leadership will be required if these ideas are going to be accepted by the public.

Long-term Residue Harvesting Contracts

A major barrier to increased wood energy development may be the lack of guaranteed fuel supplies at reasonable and stable prices. A possible solution to this problem would be to develop long-term residue removal contracts with public agencies managing forest land (contracts guaranteeing residue removal rights for up to 10 years at an agreed-upon stumpage fee). With a guaranteed supply and a fixed price, a wood energy supplier could provide information for potential users so they can assess the competitive position of wood fuel in relation to their current fuel. This information is

essential to determine the potential gains from using wood. Without guaranteed supplies, wood energy users face unknown risks of wood fuel shortages or rapidly escalating wood prices. Reducing this risk may be a key element.

A long-term residue removal contract could be written to include only residues from harvested sites or it could include the rights to material in otherwise unmerchantable low-quality stands. Interest in pursuing the use of long-term residue removal contracts as a means of increasing fiber utilization is not widespread in the public sector. Reasons for this lack of interest include: (1) loss of control over land use when contract rights are given for long periods, (2) risk of revenue loss if wood fiber prices rise significantly, and (3) realization that long-term contracts would favor one resource-using sector over all others. These concerns are important and when combined may seriously limit the use of long-term contracts.

Reducing Stumpage Prices

Reducing stumpage prices or even negative pricing may be necessary to encourage removing the residue that would otherwise be left in the woods. Many benefits accrue from increasing the level of wood residue utilization. These potential benefits include: (1) recovering material already paid for through land management activity and fire protection, (2) adding new revenue to loggers—however small, (3) reducing the regeneration costs for establishing the next timber stand, and (4) capturing a forested area's future productivity, which may be foregone without price incentives. If lower prices for residue are found to be the key link to increase utilization, consideration should be given to such an approach. The benefits from increased utilization could be set against the loss in revenue or the cost of the subsidy. The price of residue could be set so that benefits are greater than any costs incurred. This simple concept to encourage greater resource use is often resisted because the public may perceive it as giving timber away. If this perception did develop, it could damage the efforts of public forest administrators to properly manage the forest resource. This problem, however, could possibly be eliminated with a program to detail the benefits of reduced stumpage prices or negative pricing.

Reduced prices could be instituted on a trial basis in an area that presently has an active wood energy market. During this trial, an appropriate pricing system for residue removal could be developed. Using open bidding for residue sales could encourage a free market activity in which an optimal price could be established.

Joint Timber Harvest Scheduling

Public agencies managing timber on land owned by several parties could schedule timber harvesting for all or selected portions of the forest land. Such action may encourage more efficient management of the timber resource and could increase wood residue utilization. Larger timber sales may encourage the use of more economical wood residue recovery equipment. Opportunities for securing better, less costly access to forest sites and the availability of larger volumes of residue material could encourage more efficient use of whole-tree harvesters and related equipment. Timber purchasers could be spared the costly and time-consuming process of moving from one small site to another.

Joint timber harvest scheduling could only be accomplished with substantial cooperation among local, State, and Federal forest landowners. Their differing goals, perspectives, and clientele may preclude such cooperation. Small-scale cooperative efforts, however, could be tested. If the approach proves ineffective, the cost of failure would be small.

Long-term Planning

Recognizing wood energy and wood fiber utilization goals in long-term forest planning processes is an additional method for improving wood residue utilization. Incorporating such goals would allow forest managers to focus on residue utilization goals and a means of achieving them. Including potential benefits and costs of increased wood residue use in Statewide forest plans would alert forest managers to the possible impacts of such a use. With proper planning, negative impacts could be reduced while the full potential of positive impacts could be realized.

Transportation Systems

Improving wood residue utilization depends on an adequate transport system including forest roads, State highways, rail, and water transport systems. Suggestions for improving transportation systems at the State level have been suggested (Commission on Wood Products 1983). The [Minnesota] Governor's Commission on Wood Products recommended the following six-point program in 1983:

- Finance road improvements according to the "State Forest Road Plan."
- Increase the priority of State and county highway improvements within the forested areas of the State.
- Support and improve the "Minnesota Rail Service Improvement Program."
- Permit a 10-percent tolerance in forest products vehicle weights if loaded in woods or other places where scales are not available.
- Investigate opportunities to improve forest products shipping.
- Standardized State and Federal load width standards.

Road and other transportation improvements require substantial amounts of capital from State and Federal governments. Such large capital investments are unlikely unless funds from gasoline and highway taxes become available. Improved transportation is not the major barrier to increased residue utilization. Yet without substantial improvements in current transportation systems, forest residue utilization will be inhibited.

Heating Government Facilities With Wood

County, State and Federal governments can make a stronger statement about wood fuels by using wood energy themselves. At the present time, few government agencies have examined or actually installed wood-burning boilers or generators. Although there is some risk, the number and history of current wood fuel users should indicate its reliability. Considering the many potential benefits of increased wood fiber utilization, State officials could easily assume the lead in this respect. Such actions may be a dramatic catalyst for developing a wood fuel market and bringing wood into the forefront as a major alternative fuel source within Minnesota.

Wood Energy Specialists

Specialists in wood residues and wood energy could enhance wood residues use. These persons could be assigned to the staffs of the Minnesota Department of Natural Resources, the University of Minnesota, and county governments where they would concentrate exclusively on pursuing innovative methods and programs to stimulate increased utilization of wood energy. Using wood energy specialists has proved to be successful in other parts of the nation—wood residues used for energy increased dramatically as a result of staff promoting wood as an alternative fuel source. Hiring wood energy specialists would require government funding but costs are modest. The positions could be temporary (i.e., approximately 5 years), after which time the wood fuel market should be sufficiently established so that government support is no longer necessary.

Tax and Financial Policies

The area of tax and financial incentives is a complex area and provides many opportunities. Incentives must be carefully designed to prevent subsidization of overly risky proposals or to pay for projects that would "normally" occur without government assistance. Tax programs should not create unwieldly administrative problems nor lead to fiscally irresponsible allocations of public capital.

Government Guaranteed Loans

The capital cost of wood energy systems can be prohibitive given the high and often unknown risks associated with such investments. With government guaranteed loans the risk to a lender is significantly reduced. And by lowering the risk, private lenders are encouraged to lower the interest rate charged to wood energy projects. Positive results may be achieved with minimal costs if loan application approvals are carefully monitored. Loan guarantees can serve as a low-cost method to spur development within the wood energy market.

But government loan guarantees also have problems. When a guaranteed project fails, the public is required to repay the privately financed loan. Sound program administration is the key to limiting such defaults.

Increased Local Funding

Wood energy projects can be increased by direct local government financial support. In Minnesota, the Iron Range Resources and Rehabilitation Board (IRRRB) and the Arrowhead Regional Development Commission (ARDC) have provided development capital to energy projects. Here, too, financial support must be directed to projects offering the highest probability of economic benefits, i.e., those that create jobs, increase local income, and have the lowest risk.

Tax on Non-wood Energy Sources

Coal is not mined in Minnesota. An import tax on coal shipped into Minnesota could have several advantages. First, it could provide an incentive for using wood-produced energy. Second, it could have a positive effect on economic development in the depressed areas of northeastern Minnesota by employing more loggers, truckers, and related service people. Third, it could lessen the extent of the acid rain problem because coal has been identified as a major contributor to this problem.

A coal import tax also has serious disadvantages. Its adoption would be very controversial and would definitely meet strong opposition from coal-using energy producers and possible retaliatory import taxes on products shipped from Minnesota. Because little is known about the relation between the size of such a tax and its effect on wood used for energy, a coal import tax may be highly counterproductive. Then, too, economic development may be reduced as a result of increased energy costs. Some sectors, such as iron mining, that use large amounts of coal for energy may be placed under excessive pressure considering their already tenuous hold on profitability. It would seem more logical to seek ways of lowering their costs rather than raising them.

APPRAISING PROGRAM AND POLICY OPTIONS

Many policy and program options are available for encouraging the use of wood residues, each has advantages and disadvantages. To wisely choose from among such options, they must be systematically evaluated. Following is an evaluation; it was prepared by defining the evaluation criteria, summarizing program approaches previously discussed, applying criterion to program options, and developing observations and conclusions. The criteria used to judge program and policy options were (Wheatcraft *et al.* 1984):

- importance of problem (barriers) to the utilization of wood residues
- financial investment (public sector only) required to carry out the program
- government coordination required
- degree to which the program area will encourage wood residue utilization
- degree to which the program area will enhance economic activity (e.g., employment, income, stability)
- likelihood of success
- cost effectiveness
- period of time over which program area would be accepted and adopted
- potential acceptability by government, wood industry, and the public.

The ratings we assigned were: H = high; M = moderate; L = low; and NA = not applicable. Because empirical evidence relating criterion to program areas is limited or nonexistent, the ratings are highly subjective. Furthermore, because the scale of program areas differs markedly (e.g., deregulation of fossil fuel prices versus a new wood utilization extension position), it is difficult to judge the outcome of a program. And last, alternative program areas are evaluated in a discrete fashion; certainly combining program areas would result in synergistic effects (table 1).

A Policy Program Proposal

Public programs to enhance wood residue use would provide benefits that probably would not have been achieved if left to traditional market systems. But public involvement to encourage wood residue use must be well designed and properly planned. A thorough understanding is necessary of public program objectives and the steps necessary to achieve them. Expectations should be realistic so that the risk of failure is minimal. Because programs to enhance wood residue utilization are new and often untried, they should be designed with some flexibility so as to accommodate unforeseen technical, economic, and administrative events. Program managers and planners must carefully monitor progress toward agreed-to objectives. Implementing wood utilization programs will require the involvement of many user and problem-solving groups (USDA Forest Service 1980). Federal, State, and local land managing agencies; universities; private consultants; research organizations; industrial entities; and trade and dealer associations must communicate and coordinate efforts to achieve program objectives efficiently and effectively. In addition, program success at the State level will rest heavily on:

- legislative appropriation of State funds,
- governor's personal leadership,
- State university participation via research and extension programs,
- State and county forest management agencies working to support the use of wood for fuel, and
- visible demonstrations of wood supply and commercial, industrial, and institutional applications within the State.

With the above criteria in mind, a set of policies and programs to encourage the use of wood residues in Minnesota can be developed. It should not be viewed as "the final word" but rather as a starting point for discussion and debate. Specifically, a wood residue program in Minnesota could entail the following:

- develop a wood energy plan under the direction of a wood energy coordinator,
- emphasize educational and technical assistance programs to promote wood energy,
- convert public buildings to wood energy,
- plan forest management programs focused on wood residue,
- provide long-term contracts for sale of residues or otherwise unmerchantable public timber, and
- develop a guaranteed loan program for investments in wood energy projects.

The most important step in establishing a wood residue program is to develop a wood energy plan. Such a plan should outline goals, describe programs and resources required to implement it, and focus on northeastern Minnesota. The plan should be constructed with input from all interested parties and should describe the level of effort expected from each participant. It could best be developed under the leadership of a designated wood energy coordinator and should focus State efforts on especially meritorious projects. Cogeneration, large- and small-scale process steam projects,

Table 1. Appraisal of public programs to promote the use of wood residues in the production of energy.

Program Areas	Appraisal Criteria: Importance of Problem Area	Cost of Implementing	Government Coordination Required	Impact on Residue Utilization	Economic Impact	Likelihood of Success	Cost Effectiveness	Timing of Adoption & Impacts: Near Term	Short Term	Long Term	Potential Acceptability: Government Policy Makers	Public Forest Managers	Wood Industry Officials	General Public
EDUCATION														
A. Expand forest landowners' knowledge of forestry and wood residues	H	L	H	L	L	L	M	L	M	M	H	H	H	H
B. Expand knowledge of wood energy among														
- public agencies	H	L	H	M	M	M	M	M	H	H	M	H	M	H
- small businesses	H	L	H	M	M	M	M	L	M	H	H	H	M	H
- large businesses	L	L	H	L	L	M	M	L	M	M	H	H	M	H
- residential consumers	L	L	H	M	L	L	L	L	L	M	H	H	H	H
C. Increase training of wood harvesting labor force to improve utilization efficiency	M	L	M	M	M	M	M	L	M	H	H	H	H	M
D. Develop and expand technical assistance workshops on wood burning technology	L	L	L	L	L	M	M	L	M	H	H	H	H	H
E. Encourage wood industry to increase educational assistance on wood residues	M	L	L	M	L	L	M	L	L	L	M	H	M	H
F. Establish and fund wood utilization extension specialist	M	M	L	M	M	M	M	L	M	M	L	H	H	M
G. Establish and fund wood energy utilization extension specialist	M	M	L	M	M	M	M	L	M	M	L	H	H	M
REGULATION														
A. Establish stringent wood utilization standards for														
- public forest land	M	M	M	M	M	L	M	M	M	M	M	L	L	M
- private forest land	M	M	M	M	M	L	L	L	M	M	L	L	L	L
B. Deregulate price of all fossil fuels	H	L	H	H	H	M	H	H	M	M	M	NA	L	L
C. Strictly enforce rules requiring public utilities to purchase cogenerated power	H	L	H	L	M	H	H	L	L	L	M	NA	NA	H
FINANCIAL														
A. Tax incentives														
- investment credit	M	H	M	M	M	M	M	L	M	M	M	M	M	M
- accelerated depreciation	M	H	M	L	L	L	L	L	M	M	M	M	M	M
- production credits for wood fuel	L	H	M	L	L	L	L	L	L	L	L	M	M	L
- pollution control credit	M	H	M	L	L	L	L	L	L	L	L	M	M	M
B. Financing														
- revenue bonds	M	M	M	M	M	M	M	M	M	M	L	M	M	M
- loan guarantees	M	M	M	M	M	M	M	M	M	M	L	M	M	M
TECHNOLOGY														
A. Expand research on:														
- wood residue harvesting equipment	M	H	M	M	M	M	M	L	M	M	L	M	M	M
- wood residue delivery equipment	M	H	M	M	M	M	M	L	M	M	L	M	M	M
- wood fuel combustion efficiency	L	H	M	M	L	L	L	L	M	M	L	M	M	M
ADMINISTRATIVE														
A. Prepare and adopt statewide wood energy plan	H	M	H	M	M	M	M	M	M	M	M	M	M	M
B. Identify wood residue objectives and programs in long-term timber management plans	M	L	M	M	L	M	M	L	M	M	M	M	M	M
C. Intensify state and regional forest resource studies	M	L	M	L	L	M	M	M	M	M	M	M	M	M
D. Establish and fund wood energy coordinator position	M	M	L	M	M	M	M	M	M	M	M	M	M	M
E. Develop and expand use of wood energy demonstration projects	M	M	M	M	M	M	M	L	M	M	M	M	M	M
F. Encourage use of wood generated energy in public buildings	M	L	L	M	M	M	M	M	M	M	M	M	L	M
G. Increase funding emphasis on														
- reforestation	M	M	M	L	L	M	M	L	M	M	M	M	M	M
- forest management	M	M	M	M	M	M	M	M	M	M	M	M	M	M
H. Improve and expand forest road systems	M	M	M	M	M	M	L	M	M	M	L	M	M	L
I. Adopt joint scheduling of public timber harvests	L	M	M	M	L	L	L	L	L	L	L	L	M	M
J. Initiate new residue pricing policies														
- negative pricing	M	M	L	M	M	M	M	M	M	M	L	L	M	L
- residual removal credits	M	M	L	M	M	M	M	M	M	M	M	L	M	M
K. Establish long-term wood residue utilization contracts	M	L	L	M	M	M	M	L	M	M	L	L	M	M

• Ratings of program areas are: H = high, M = moderate, L = low, and NA = not applicable.

and district heating programs are worthy of attention. Small-scale process steam projects appear to have special merit for the use of wood residues.

In addition to designing a wood energy plan, establishing a wood energy marketing system also is essential. Only through the use of such a system can the cost of wood biomass become competitive and supplies to consumers be dependable. As previously discussed, consumer apprehension about wood fuel supplies is a major factor limiting conversion to wood energy. Wood energy conversions in public buildings and forest management activities designed to assure residue supplies could enhance marketing projects. Extension programs may be a good way to inform wary consumers of wood energy opportunities.

Public forest management and timber harvesting programs should encourage reliable and accessible supplies of wood residue for energy. Harvesting low quality, understocked, or stagnant timber stands could create substantial wood residue supplies and allow more intense timber management practices in newly established stands. Long-term wood residue removal contracts may encourage wood-residue use.

State authority to develop and implement a loan guarantee program encouraging investments in wood energy projects should also be considered. If properly administered, such loans could ease the investor's financial burdens by enabling lending institutions to charge lower interest rates—rates consistent with the real risk. Such a program could involve limited State financing if projects are wisely chosen and mechanisms for collecting administrative costs are established.

Minnesota is faced with an opportunity to enhance the use of wood in a fashion that will encourage energy conservation and economic development. This opportunity is especially noticeable in the State's northeastern region. The resources required to capture such an opportunity are not overwhelming, so investing in a comprehensive wood residue utilization program should be seriously considered.

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ENGINEERING AND ECONOMIC CONSIDERATIONS OF WOOD ENERGY SYSTEMS USING WOOD CHIPS AND PELLETS[1]

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Wood alone cannot remedy future shortfalls in the Nation's energy supply. Rather, wood belongs to the growing category of supplementary fuels that together will fill this gap. In addition to providing an alternative energy source, the use of wood fuel can result in annual cost savings for a facility, have a positive economic impact on local and regional areas, and improve forest management practices.

The use of wood for energy has continued to increase since the early 1970's—first in the forest products facilities that had existing residues and more recently in other industrial, commercial, and institutional applications. Recently the rate of conversions to wood fuel has declined partially due to stabilized fossil fuel prices, and the fact that many of the most cost effective conversions have already been completed. But as fossil fuel prices continue to rise, conversions will again increase.

Although wood fuel is not a solution to the energy needs of all facilities, in many cases it may provide an economically viable alternative to fossil fuels. The primary benefits of using wood as an energy source are as follows:

1. Fuel cost per million Btu is usually significantly lower than other fuels.
2. Wood, when burned properly, does not create appreciable air pollution.
3. Wood can be a more reliable fuel source than fossil fuels under certain conditions.
4. Local wood production creates more jobs and retains more energy dollars in the State than fossil fuels do.
5. New opportunities for marketing low-quality wood could improve the profitability of stand conversions, precommercial thinnings, and other forest improvement operations which would result in the production of higher value timber at lower cost.

This paper provides a summary of a study conducted to analyze the equipment requirements and the delivered energy cost of wood energy systems using wood chips and pellets (Steklenski and Haygreen 1983). In addition, we analyzed how wood fuel price, interest rate, and non-fuel annual cost would affect the total annual cost of each system.

WOOD ENERGY SYSTEM EQUIPMENT

The development and production of equipment used in wood energy systems has advanced dramatically over the last 10 years. Current systems can be designed to be highly automated and with routine maintenance will be very dependable. However, there are inherent limitations with equipment designed for use with wood fuel. One cannot expect even the most automated wood energy system to be as easy to operate as a natural gas or oil system, but that gap has been reduced significantly. The success of each system depends substantially on the engineers that design that system and oversee its installation. Many engineering firms have gained a wealth of knowledge, and it is important that this knowledge be put to use.

[1] *Wolf and Associates, Inc., St. Paul, Minnesota, served as a consultant during this study. A cooperative study by the Department of Forest Products, University of Minnesota; and Research Work Unit FS-NC-4802, North Central Forest Experiment Station, Forest Service, USDA, Duluth, Minnesota. Partially funded by Forest Service, USDA, under Cooperative Agreement No. 23-82-18.*

Wood energy system equipment can be divided into two general categories: (1) handling, preparation, and storage equipment and (2) energy conversion and pollution control equipment.

Wood fuel is bulkier and of lower energy density than fossil fuels. Therefore, to provide adequate fuel inventories, handling and storage equipment is an important part of any wood energy system. It is in this area that the most equipment failure has occurred. Most problems occur when wood fuels that differ from design specifications are passed through a system. Three of the most important fuel parameters that relate to the operation of storage and handling equipment are fuel size, moisture content, and bulk density. A system designed specifically to store and handle a densified wood fuel such as pellets won't operate, in most cases, with wood chips or bark. A system could be designed for multiple fuels, but that decision should be made in the initial engineering phase of the project. Therefore, wood energy users should be aware of their fuel supply situation and design and operate their system accordingly. One method of assuring this is to incorporate specifications of the above mentioned fuel parameters in all fuel purchase agreements.

Despite past problems with storage and handling equipment, great advancements in equipment and system design have taken place in recent years; with careful planning, a reliable handling and storage system can be built.

Energy conversion equipment is often similar to that used for coal burning systems. In some cases existing fossil fuel combustion systems can be retrofitted to burn wood at a fraction of the cost of a new wood combustion system. As with handling and storage equipment, wood combustion equipment is now being designed to account for the unique properties of wood fuels and is therefore able to handle a wider range of wood fuels more efficiently. However, every wood combustion system does have limitations in regard to the fuel moisture content, size, and ash content at which it will operate. Therefore, the system must be carefully designed if it is to operate efficiently.

Currently, particulate matter and visible emissions appear to be the only emissions of concern produced by non-residential wood burners. The quantity and quality of these emissions is very site specific and depends on the type of combustion system, fuel type, and operating conditions of the burner.

Visible emissions are the result of poor combustion control, fuel variances, operator inexperience, misapplication of burner design, or some combination of the above (Junge 1977). Control of visible emissions, therefore, is often a matter of improving the operation of the combustion system.

Particulate emissions, which include fly carbon and inert materials, are a function of boiler firing practices and the amount of inert material entering the furnace. Particulate emissions range from less than a sub-micron up to 2 millimeters in size (Junge 1979). Some form of particulate emission control is generally required if a combustion system is to comply with State and Federal air quality regulations. This control may take place within the burner or after combustion gases exit the burner. In most cases particulate emissions can be kept at acceptable levels with commercially available equipment.

ECONOMICS OF WOOD AS A FUEL SOURCE

It is useful to review the basic economic framework of a decision to convert from an oil or natural gas system to a wood fuel system. We can compare the two systems in the following ways:

Oil/natural gas	**Wood**
1. Expensive fuel	1. Inexpensive fuel
2. Easy to use	2. More difficult to use
3. Inexpensive to convert	3. Expensive to convert

Wood fuel is economically attractive because it is less expensive than oil or natural gas on a net energy basis. A decision to convert to wood fuel is made if the anticipated fuel cost savings are sufficiently greater than the incremental increases in capital investment cost, operating and maintenance costs, and other miscellaneous costs. The following section provides general information regarding the above cost factors.

Fuel Cost

Fuel price depends on type of fuel, moisture content, quantity purchased, transportation distance, local supply and demand situation, and type of fuel processing. Typical prices range from $10 to $25 per ton for wood chips and from $50 to $60 per ton for densified wood fuel.

Wood fuels are commonly purchased on a dollar per ton basis; however, to account for the significant effect moisture has on a fuel's usable heat, it is more appropriate to compare fuel cost on a dollar per million Btu basis. Equation [1] is used to calculate fuel cost on the dollar per million Btu basis. As can be seen from this equation, moisture present in the fuel, the associated conversion efficiency, and the heating value of a fuel are accounted for in determining fuel cost.

Table 1.--Comparison of fuel costs for various fuels

(In $/million Btu)

Fuel type	Cost (Dollars)	Heating value	Moisture content	Efficiency (Percent)	$/MMBTU
Natural gas	4.65/MCF	MMBTU/MCF	--	0.80	5.81
#2 oil	.90/gal	138,000 BTU/gal	--	.80	8.15
Wood pellets	60/dry ton	17 MMBTU/dry ton	0.08	.78	4.92
Wood chips	20/dry ton	17 MMBTU/dry ton	.45	.65	3.29

$$\$/\text{MMBTU} = \text{Fuel cost (\$/unit)} \times \frac{\text{Unit}}{\text{MMBTU}} \times \frac{1}{(1-\text{MC})} \times \frac{1}{\text{Conversion Efficiency}} \quad [1]$$

The fuel costs, using equation [1], of various fuels are compared in table 1. Wood fuels, at these selected fuel prices, have a significant cost advantage over oil and natural gas.

Capital Investment Costs

The capital investment required for the conversion of a facility includes the cost of the following equipment:

1. Unloading
2. Fuel handling and storage
3. Energy conversion
4. Pollution abatement
5. Control systems

Additional capital investment may be required for constructing buildings and roads, or modifying an existing structure. Captial investment cost of a wood fuel system ranges from 2 to 10 times that of a similar size oil or natural gas system and is primarily influenced by system capacity, fuel type, type of equipment used, degree of automation, system flexibility, and site-specific factors (MN DEPD 1983).

Installation Cost

Installation cost generally represents from 10 to 50 percent of the capital equipment cost and depends on the type of equipment to be installed and site-specific factors. However, these costs have been reduced for many small to medium, wood energy systems through modular construction techniques and systems that are almost completely shop fabricated.

Operating and Maintenance Costs

The operating and maintenance costs for wood fueled systems vary with fuel type, equipment selection, degree of automation, and maintenance schedule. These costs will be several times greater than those of equivalent size oil or natural gas systems because of increased labor requirements, maintenance costs, and electrical power requirements.

More labor is required to remove ash from the fire box and to clean the boiler more frequently than with oil or natural gas. The increase in equipment to store and handle wood fuel can increase maintenance costs approximately 200 percent (MN DEPD 1983). Increased electrical costs are due to the need for electrical motors for handling equipment, the combustion unit, and pollution control equipment. The incremental cost associated with these power requirements depends on the size of the system and the electrical energy rates.

Miscellaneous Costs

In addition to increased operating and maintenance costs, wood energy systems may also face increased insurance costs and property taxes. However, this is very site specific and should be carefully evaluated by each facility contemplating a conversion to wood fuel.

As mentioned above, a decision to convert to wood fuel is evaluated on the basis of anticipated annual fuel cost savings versus the incremental increase in capital investment cost, operating and maintenance costs, and other miscellaneous costs. Therefore, any policies or legislation that can enhance one or more of these economic factors will likely increase the number of facilities converting to wood fuel. But in some cases, even with such incentives, a facility may chose to continue to use oil or natural gas because of convenience, the desire to concentrate on the primary business interests, or simply a resistance to change.

ECONOMIC ANALYSIS

The purpose of the research described below was to investigate the economic relationships associated with wood energy systems and to determine cost and engineering information for a wide range of potential wood fuel users. In addition, results of the economic sensitivity analysis can be used as a guide for developing public policy or legislation that will provide suitable incentives to increase the quantity of wood used as fuel.

The project did not directly compare wood fuels with fossil fuels because many existing studies conducted this type of analysis or provided the necessary procedures to do so (Banta 1979, Ekono Inc. 1982, Harpole *et al.* 1982, McGowan and Walsh 1980, and Pulaski *et al.* 1981). Additionally, such comparisons are commonly very site specific and of limited use for most potential wood energy users.

Six energy systems ranging in output from 0.4 to 200 million Btu per hour were analyzed in detail to develop a broad range of costs for chip and densified wood energy systems. A densified wood fuel system was not considered for the 200 million Btu per hour system because of difficulties that would be associated with supplying the approximately 100,000 tons of densified wood fuel required annually. The capacity, use, and potential users of each system studied were:

System Capacity (10^6 Btu/hr)	Use	Potential Users
0.4	Space heating	Small commercial buildings (i.e. small apartment building, store, office)
0.8	Space heating	Medium commercial building
7.5	Space heating	Large commercial, school, or hospital building
25	Space and process heating	Medium industrial and heating district heating
90	Space and process heating	Large industrial and district
200	Space and process heating	Pulp and paper mill

We used a method of analysis based on current costs to evaluate each energy system. The cost of each system is reported as the annual cost per million Btu per year and is termed the delivered energy cost. This method allows for easy comparison of alternatives within and between systems. Alternative assumptions analyzed include variations in fuel type, storage capacity, fuel price, interest rate, and non-fuel annual cost.

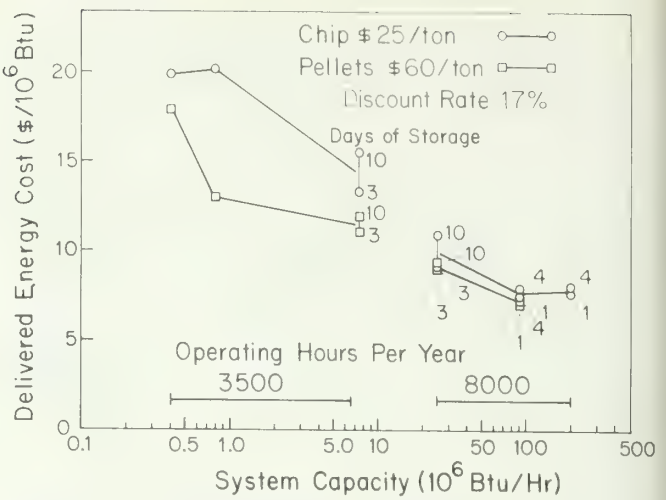


Figure 1.—*Delivered energy cost of densified wood and chip fuel energy systems for six representative energy users.*

The assumptions regarding equipment selection and cost calculations for each system are presented in detail in Steklenski and Haygreen 1983. These assumptions were developed from the following sources: (1) equipment manufacturers, (2) engineering firms, (3) existing wood energy systems, and (4) published information. Because of the site-specific nature of wood energy systems, these assumptions represent only one of many design possibilities and may be altered to accommodate other scenarios. In addition, sufficiently detailed cost information is provided so that other economic analysis methods can be used if desired. If a site-specific evaluation of economic feasibility is required, several computer programs are available for wood energy economic analysis (Harpole *et al.* 1982, Laulainen 1981, and Pulaski *et al.* 1981).

Delivered energy cost and annual cost information for the range of chip and densified wood fuel systems considered is summarized in figures 1 and 2. Given the

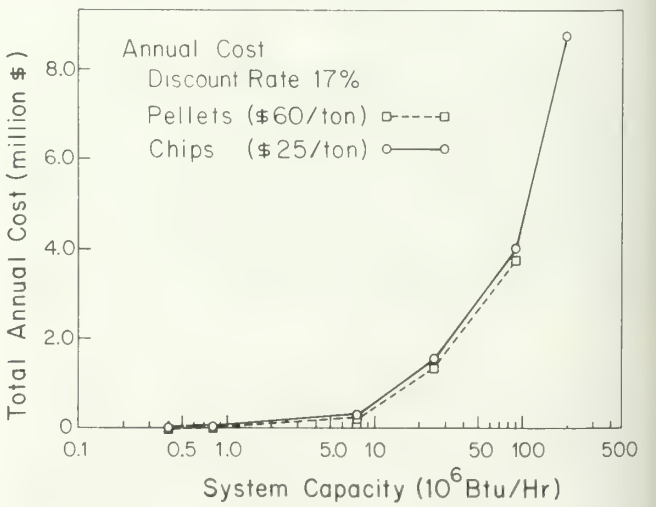


Figure 2.—*Total annual cost of densified wood and chip fuel energy systems for six representative energy users. Costs are presented for the largest storage capacity option of each system.*

assumptions and analysis procedure we used, a chip price of $25 per ton, and a pellet price of $60 per ton, the following conclusions can be drawn:

1. At the chip and pellet prices assumed in this analysis, densified wood fuel systems have a lower delivered energy cost and annual cost than chip systems of equivalent size and storage capacity. The lower costs result from the chip and pellet price differential and the improved handling and combustion properties of densified wood fuel.

2. Larger wood energy systems have lower delivered energy costs than small systems because the larger process heating systems operate more hours per year and take advantage of economies of scale.

3. The larger storage capacity required by chip systems results in larger delivered energy cost than for densified wood fuel systems of equivalent size. Again, this is a result of the improved storage and handling properties of densified wood fuels.

4. Delivered energy costs for the specific systems studied did not always conform to anticipated trends, e.g., the increase in delivered energy cost between the 0.4 and 0.8 million Btu per hour systems. This was a result of the size and variety of storage, handling, and combustion equipment selected. A range of delivered energy costs where each system's specific variations have been smoothed is presented in figure 3. These results are more indicative of overall cost trends that occur with wood energy systems.

The following section shows how changes in several of the assumptions affect the delivered energy cost and annual cost of various-size wood energy systems. The variables and level of variation chosen for each assumption were:

Variable	Level
Wood fuel price	Chips—$15, $25, and $35 per ton Pellets—$50, $60, and $70 per ton
Interest rate	14, 17, and 20 percent
Non-fuel annual cost	± 25 percent

These values were selected arbitrarily and are not necessarily intended to predict future events. We calculated the delivered energy cost and annual cost of each system for each alternate condition using the assumptions and cost analysis procedure outlined in Steklenski and Haygreen 1983.

Conclusions regarding the sensitivity of the delivered energy cost to variations in fuel price, interest rate, and non-fuel annual cost are as follows:

1. Wood fuel price changes result in unit energy cost changes, which are equivalent for all systems. However, the annual cost of larger wood energy systems is more sensitive to fuel price than that of smaller systems because a larger proportion of total costs of large systems go for fuel. In addition, densified wood fuel systems are more sensitive to fuel price than chip systems.

2. The delivered energy cost, as well as the annual cost, of smaller wood energy systems is more sensitive to interest rates and non-fuel annual cost than that of larger systems because the proportion of capital and other costs except fuel is greater for small systems. In addition, chip systems are more sensitive than densified wood fuel systems.

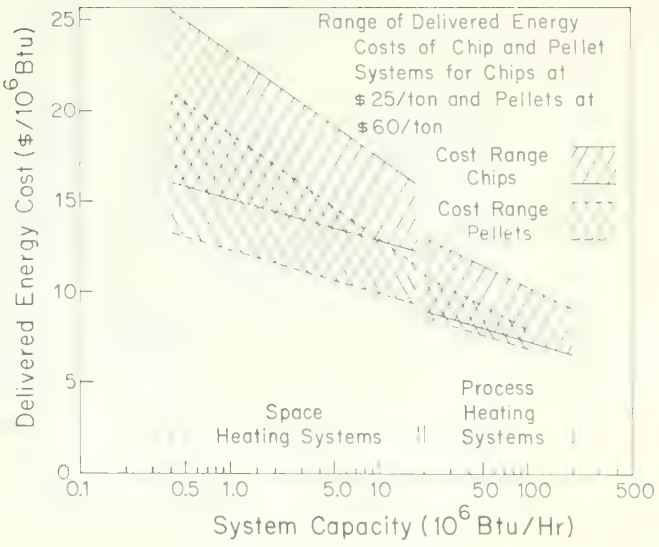


Figure 3.—*Range of delivered energy costs of densified wood and chip fuel space and process heating systems with a fuel price differential of $35 per ton.*

We also compared chip and densified wood fuel systems, using two fuel price scenarios. Systems using the lowest priced chips were compared with systems using the highest priced pellets (a $55 per ton differential); and systems using the highest priced chips were compared with systems using the lowest priced pellets (a $15 per ton differential).

The chip and pellet price differential is a major factor in determining the cost competitiveness between chip and densified wood fuel energy systems. In process energy systems, a fuel price differential of $40 to $50 per ton between chips and pellets will result in equivalent delivered energy costs. This differential in space heating systems, by contrast, ranges from $70 to $100 per ton. This indicates that densified wood fuel systems, such as those burning pellets, are more economical for systems with small energy requirements (less than 7.5 million Btu per hour); chip-fired systems are more economical for systems with larger energy requirements. Figure 4 presents this relationship graphically by assuming a $45 per ton price differential for the entire range of systems considered.

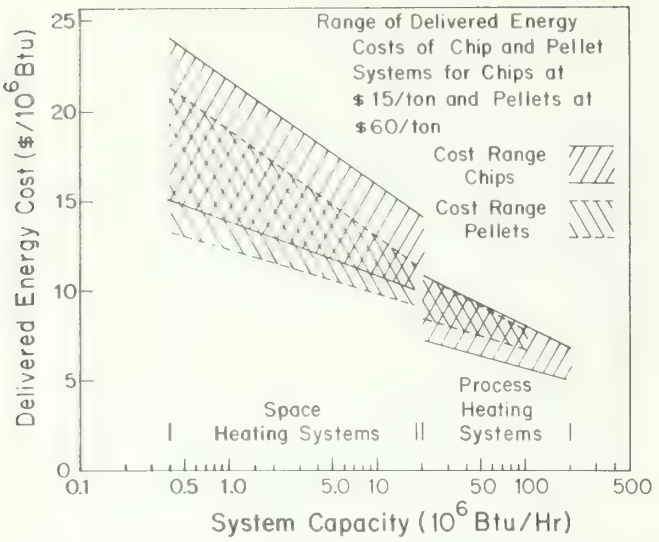


Figure 4.—*Range of delivered energy costs of densified wood and chip fuel space and process heating systems with a fuel price differential of $45 per ton.*

CONCLUSION

Facilities and individuals base their choice of an energy system primarily on annual cost savings. A decision to convert to wood fuel is evaluated on the basis of anticipated annual fuel cost savings versus the incremental increase in capital investment cost, operating and maintenance costs, and other miscellaneous costs. An understanding of this relationship and the results of the economic sensitivity analysis presented above can be useful in developing public policy and legislation to enhance the conversion of additional facilities to wood fuel energy systems.

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Achieving wood energy potentials: evidence in northeastern Minnesota. 1987. Gen. Tech. Rep. NC-114. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 82 p.

A study of wood energy potential in northeastern Minnesota concludes that (1) the forests of the region could support a much larger wood energy harvest without significant cost increases for other forest products; (2) existing stands are predominantly overmature and cutting more now will enhance future wood supplies for all users; (3) converting to wood energy could reduce fuel costs for many consumers, businesses, and industries; (4) a wood energy industry would increase the region's output and employment and reduce the costs of its exports; and (5) most barriers to expanded wood energy use are institutional, not technical. Policies to encourage wood energy development can be developed at low cost.

KEY WORDS: Timber supply, economic impact, forest policy, harvest scheduling, biomass energy.

United States Department of Agriculture

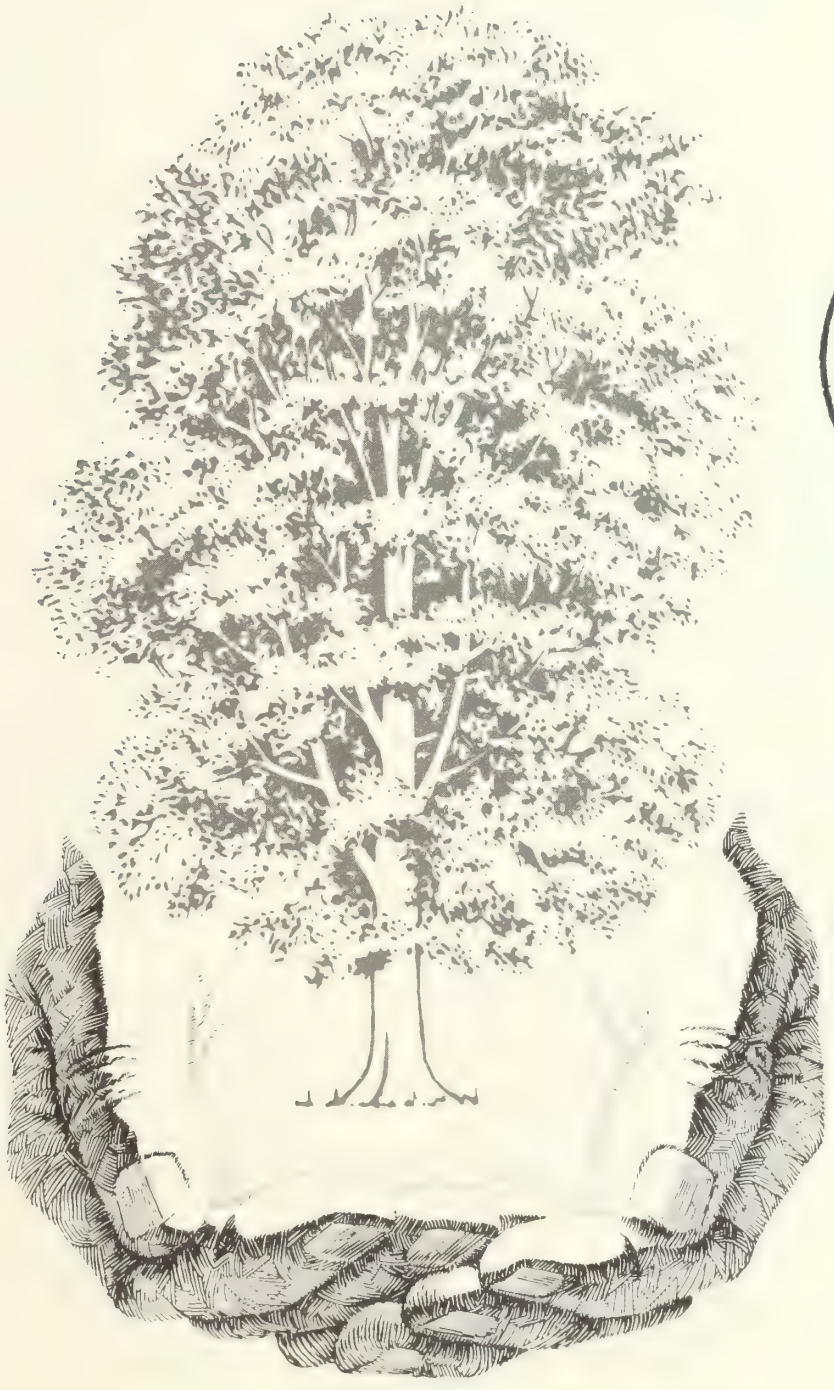
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General Technical Report **NC-115**

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1987. Managing black ash in the Lake States. Gen. Tech. Rep. NC-115. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

Provides a guide for managing lowland hardwoods in the Lake States. Gives both even-age and uneven-age guides for black ash.

KEY WORDS: *Fraxinus nigra*, lowland hardwoods, swamp hardwoods, black ash-American elm-red maple type, management.

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MANAGING BLACK ASH IN THE LAKE STATES

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In the Lake States black ash occurs most frequently in the black ash-American elm-red maple type (SAF type 39).[1] It is the major hardwood type on lowlands in the northern Lake States region with black ash (*Fraxinus nigra* Marsh.), American elm (*Ulmus americana* L.), and red maple (*Acer rubrum* L.) as the predominate species. The type is commonly called lowland hardwoods or swamp hardwoods. Black ash occurs on 2,567,000 acres of commercial forest land in the elm-ash-soft maple type in Michigan (Raile and Smith 1983) and Wisconsin (Smith 1986). More than three quarters of this acreage is suitable for saw log production (SI_{50} > 50). Black ash is the preferred species and dominates the type in northern Wisconsin and the Upper Peninsula of Michigan. Elsewhere in Michigan and Wisconsin, red maple dominates the type but black ash still accounts for a large share of the growing stock. In Minnesota black ash occurs on 683,000 acres of commercial forest land in the elm-ash-cottonwood type within the Aspen-Birch, Northern Pine, and Central Hardwood Survey Units (Jakes 1980). More than half of this acreage is suitable for saw log production. Here, black ash, American elm, and red maple comprise the majority of the stocking but black ash generally is more abundant than the other two species. Dutch elm disease has almost eliminated the elm, and red maple is usually defective on wet sites.

The black ash-American elm-red maple type is a long-lived subclimax on somewhat poorly drained mineral soils (Braun 1964). The type grades into an almost pure black ash type, which is prevalent where drainage is very poor on the wetter organic peat and muck sites. Black ash is probably the climax species here. In the northern Lake States the type frequently grades into northern white-cedar on the wetter sites and into the hemlock-yellow birch type on better-drained areas and into tamarack or tamarack-black spruce stands in northern Wisconsin (Rudolf 1980).

Black ash is most commonly found growing in moist to wet muck or shallow organic peat soils but also grows in swamps, along small streams in gullies, and in small poorly drained depressions (Rudolf 1980). It also grows on fine sands and loams underlain by clays where surface drainage is impeded and on poorly drained sites with high water tables (Wright 1965). In the uplands, black ash is restricted to impeded drainageways where it grows on wetter than normal mineral soils and mingles with white ash, red maple, yellow birch, American basswood, and sugar maple. Trees growing on better than normal mineral soils with high water tables or impeded drainage may reach heights of 65 to 75 feet at 50 years and diameters of 18 inches at d.b.h. in 130 years.

MAJOR PROBLEMS

Black ash grows slowly on organic peats and mucks, attaining heights of only 30 to 45 feet at 50 years and about 50 to 60 feet at 100 years. D.b.h. of the best trees averages only 10 inches at 110 years and 12 inches at 130 years. Black ash seedlings, saplings, and sprouts tend to dominate the regeneration where partial openings in the canopy have occurred. Clearcuttings on organic sites often result in inadequate natural regeneration or loss of advance regeneration to rising water tables or from competition with grass and brush. This is winter habitat for deer that browse heavily on black ash seedlings and stump sprouts. Most swamp hardwood stands contain many overmature, defective, and diseased trees. Some stands have been so severely high-graded for quality trees that they are now fully stocked with poor quality trees. Many unmanaged, fully stocked stands contain no desirable advance black

[1] *This type should not be confused with other more southerly bottomland cover types of the Society of American Foresters: silver maple-American elm (type 62); cottonwood (type 63).*

ash regeneration. Trees on wet sites are shallow-rooted and subject to windthrow. Black ash is the key high value species in the black ash-American elm-red maple type because it produces wood that is free from disease and insect damage.

IMPORTANT SILVICAL CHARACTERISTICS OF BLACK ASH

Flowering and Fruiting

Black ash is polygamous (Bonner 1974). Its flowers appear before the leaves in late May or early June. The fruit is a winged, flattened, single-seeded samara that is borne in terminal or lateral branch clusters. It ripens in late August or September and is dispersed from October until early spring. Ripe seed is yellow-brown, 1½ inches long, ⅜-inch wide and averages 8,100 cleaned seed per pound (Bonner 1974). It has a wing that extends almost to the base and often is notched at the apex of the pericarp. Black ash seed is indistinct within the pericarp and has a characteristic spicy odor (USDA 1948).

Black ash bears good seed crops infrequently (Bonner 1974, Godman and Mattson 1976, 1985). Only 11 good or better black ash seed crops were produced during a 35-year observation period in northeastern Wisconsin. Good seed crops occurred at 1- to 8-year intervals with most intervening years having poor seed crops. The longest period of successive poor seed crops was 7 years (Godman and Mattson 1976, 1985).

Seed soundness can be determined by using either a cutting test or x-rays to see if a firm, white, fully-elongated seed fills the samara. Viability can be tested by using the excised embryo and tetrazolium staining methods (Association of Official Seed Analysts 1965).

Germination

Fresh black ash seed contains both an immature and dormant embryo that require warm moist and cold temperature after-ripening prior to good germination (Vanstone and LaCroix 1975). Eighty-seven percent germination was obtained by placing fresh, sound samaras in moist peat (75 percent moisture content) at 44° F for 126 days and then after-ripening them at 14° F for 168 days (Vanstone and LaCroix 1975). Before black ash embryos germinate, they must grow from about one-half to two-thirds the length of the seed (Steinbauer 1937). As a result of this, most black ash seed will not germinate until the second spring after seedfall. Some seed may lie dormant in the litter for up to 8 years (Wright 1965).

Seedling Development

Black ash seed is capable of germinating in hardwood leaf litter or under 1/4- to 3/4-inch of soil, but grass, brush, and advance hardwood reproduction must be controlled for successful black ash seedling establishment. New germinants are about 2 inches tall within 2 weeks and under the best conditions may average about 6 inches in height by the end of their first growing season. At this time, the first-year seedlings still retain their single pair of opposite cotyledons and may have up to four pairs of single, opposite, stalkless leaflets. Typical compound ash leaves are not normally produced until the seedlings' second year.

Black ash seedlings and sprouts frequently are the only advance hardwood reproduction that occurs in canopy gaps in uneven-aged stands growing on wet organic soils in the black ash-American elm-red maple type. However, on disturbed mineral soils with either a high water table or impeded drainage, the advance reproduction often is red maple, American elm, and green or white ash. On these sites black ash seedlings grow faster than red maple seedlings but grow slower than American elm seedlings (Rudolf 1980). Without disturbance, reproduction is almost entirely absent on better sites within the black ash-American elm-red maple type.

On slightly better drained sites, tree species are more abundant and diverse. Here, species more demanding in their site requirements such as white ash, green ash, basswood, yellow birch, red maple, and even sugar maple occur along with black ash.

Black ash seedlings, like white ash seedlings, initially are more shade tolerant than yellow birch and American elm. However, they become more intolerant with increasing age. White ash seedlings should receive from 55 to 75 percent shade the first year (Logan 1973). Best overall white and black ash seedling development *probably* occurs in about 45 to 50 percent of full sunlight.

Vegetative Reproduction

Black ash sprouts readily from low cut stumps up to 12 inches in diameter. Sprouts originate from adventitious buds on the sides of the stump and at the root collar. Stump sprouts can be extremely fast growers. Black ash will also produce root suckers from cut trees.

White-tailed Deer

Black ash seedlings and sprouts are heavily browsed by deer in the swamp and lowland black ash-American

elm-red maple types. Apparently they can withstand moderate to heavy winter browsing.

MANAGEMENT OBJECTIVES

Lowland hardwood stands should be managed to produce the maximum quality and quantity of high value sawtimber, pulpwood, fuelwood, and other products, consistent with the site potential. Not all lowland hardwood stands can or should be managed for timber production. Due to a raised water table and decreased transpiration, clearcutting or strip cutting on excessively wet organic peat or muck sites may result in loss of the site to brush, grass, or even cattails. On these excessively wet areas where site index is less than 45, natural succession should be allowed to continue with the objectives of maintaining wildlife habitat and watershed quality.

Silvicultural practices should be concentrated on the better drained sites where seedling and sprout regeneration can be expected. Lowland hardwoods frequently border streams and lakes where they may influence water quality, water temperature, and fish populations. Single-tree selection cutting should be considered along stream borders and lake shores to enhance or preserve these features.

On sites averaging 45 to 55 feet at 50 years, the primary objectives are to provide food and shelter for wildlife and to protect the watershed values. However, some small saw logs (10 to 12 inches in d.b.h.) and fiber can be harvested without sacrificing these objectives.

On better ash sites with mineral soils that are either somewhat poorly drained or have impeded drainage, site index averages 55 feet or more at 50 years. On these sites producing high-value sawtimber and veneer is the primary management objective with pulpwood, fuelwood, and other products as secondary objectives.

Cutting in the black ash-American elm-red maple type should be done when the ground is frozen and preferably when it is covered with snow to minimize seedling loss, improve equipment access, limit damage to the site, and provide alternative winter deer browse from the tops of felled trees.

SILVICULTURAL SYSTEMS

An examination of the diameter and age class distributions in six natural unmanaged black ash stands on the Nicolet National Forest indicates that black ash can be managed by either uneven- or even-aged management systems. Stand data obtained from sampling two lowland stands (two one-half acre plots in each; stands 1 and 2) on organic material of the Carbondale series had at least 11 different age classes (from new seedlings up to trees 94 to 241 years old) present, the typical inverse J-shaped diameter distribution, and the irregular appearance of an uneven-aged stand (table 1). On wet, organic sites black ash seedlings, stump sprouts, and saplings tend to dominate the regeneration where harvest tree-size openings in the canopy have been created by either the cutting or the death of a saw log-sized tree. The presence of black ash seedlings in uneven-aged climax or subclimax stands where single trees or small groups of trees have died is evidence that the selection management system will work on wet organic sites where watershed protection and wildlife considerations are major concerns. If the ground is frozen, individual mature, defective, and diseased ash trees can be harvested in wet swamps and lowland areas when cutting adjacent uplands.

One (stand 3) of the four stands examined (one-half acre plot in each) growing on mineral soils of the Iron River or Monico series with impeded drainage looked like an even-aged stand, but it had upper canopy trees ranging from 56 to 109 years old and the typical diameter distribution of an uneven-aged stand. Each of the three remaining stands on mineral soils had diameter distributions that closely resembled the normal bell-shaped frequency distribution of an even-aged stand (stands 4, 5, and 6). Thus, even-aged silviculture also can be used to regenerate moderately tolerant black ash seedlings, especially on somewhat poorly drained mineral soils. Because of the infrequency of good seed crops and the risks of losing the sites to grass and brush, the shelterwood cutting method appears to be the only safe even-aged cutting method to use in regenerating new black ash stands on mineral soils either poorly drained or with impeded drainage. Past clearcuttings on wet sites with poor or impeded drainage frequently have resulted in inadequate natural regeneration or complete loss of advance regeneration to grass and brush. However, the final shelterwood removal cut in mature stands is a clearcut. Clearcutting is appropriate only after adequate, established, advance black ash regeneration is present (at least 5,000 well-distributed stems per acre 2 to 3 feet tall).

The best way to obtain conditions favorable for black ash regeneration is through single-tree selection cuttings on the organic sites and through shelterwood cuttings on wet mineral soils where black ash is less tolerant. The shelterwood cutting method also can be used to regenerate black ash stands of seed bearing age that are inadequately stocked with crop type trees. This could be the best treatment for stands that previously have been high-graded for quality trees on mineral soils.

Table 1.--Diameter distributions and stand characteristics of natural black ash stands on wet organic and somewhat poorly drained mineral soils

D.b.h. class (In.)	Organic 1/		Mineral 2/			
	Stand 1	Stand 2	Stand 3	Stand 4	Stand 5	Stand 6
			Trees/A			
5	96	79	86	26	22	12
6	58	47	96	50	16	36
7	41	34	46	26	20	34
8	30	45	56	26	40	34
9	20	40	30	48	34	36
10	15	24	12	46	30	40
11	14	18	6	20	20	26
12	5	13	2	32	20	36
13	8	10	4	12	14	30
14	5	3	6	12	6	8
15	-	2	-	6	2	-
16	3	5	-	8 3/	8 3/	2 3/
17	1	-	-	2	6	6
18	-	-	-	2	-	-
19	-	-	-	2	-	-
20	-	-	-	-	2	-
21	-	-	-	-	2	-
22	-	-	-	-	2	-
Stand Total	296	320	344	318	244	300
Diameter distribution	uneven-age	uneven-age	uneven-age	even-age	even-age	even-age
Age(yrs)	1-241	1-94	1-109	71-78	79-81	78-82
Site index (SI_{50})	30	41	65	66	65	63
Basal area (ft^2/A)	94	119	99	167	144	162

1/ Stand 1 and 2 are growing on organic material of the Carbondale series; stand 1 has more than 50 inches of organic material (Euic Hemic Borosaprists) and stand 2 has 16 to 50 inches of organic material over sandy or sandy-skeletal, mixed, Euic Hemic Terric Borosaprists).

2/ The four upland stands are growing on mineral soils mapped as the Iron River Series (coarse-loamy, mixed, frigid Alfic Fragiorthods) but some may be small inclusions of the Monico Series (coarse-loamy, mixed, frigid Aquic Dystrochrepts).

3/ Most trees larger than 16 inches d.b.h. are older residual trees.

THINNING BLACK ASH STANDS

Intermediate thinnings should be restricted to stands that are less than 110 years old, contain at least 100 square feet of basal area per acre, and will have time to respond to thinning before the harvest cut.

First, reduce the residual basal area to the prescribed stocking level (80 percent crown cover for the first entry) using the even-aged stocking guide for black ash (fig. 1, table 2). The stocking guide is based on the average residual d.b.h. of all trees 4.6 inches d.b.h. and larger after thinning. The cut should be primarily from below but an attempt should be made to free crop trees from poor quality main canopy competition. Black ash has a narrower crown than sugar maple, red maple, or yellow birch. This suggests freeing crop tree crowns for only 5 feet beyond their crown perimeters in pole-size stands and from two poor quality main canopy competitors in saw log-size stands. Leave adjacent tree crowns to correct small forks (less than 2 inches in diameter). Remove high risk and cull trees with little growth and grade improvement potential to reduce mortality and upgrade the stand. Favor black ash by discriminating against other species that are growing on mineral soils with poor or impeded drainage.

Later thinnings should be delayed until crowns close and lower branches die on the crop trees. Thinnings should be made to the 90 percent crown cover stocking level to maintain growth responses and bole quality development on the main canopy stand. Cuts should be primarily from below.

Small black ash stands (less than 10 acres in size) on impeded drainageways in the uplands should be managed the same as the surrounding stand (either even-aged or uneven-aged) because in wet situations black ash has a decided advantage over associated species regardless of the management systems employed. The Manager's Handbook for Northern Hardwoods is the appropriate guide to use for managing small, upland, black ash stands (Tubbs 1977).

REGENERATING BLACK ASH STANDS

In selection stands, canopy gaps are needed to encourage black ash reproduction. All poor-quality residual stems larger than 2 inches in d.b.h. must be cut in these small openings so that vigorous regeneration can develop. Satisfactory black ash sprouts also can be obtained from stumps that are cut close to the ground. Desirable residual stocking and structure for sustained growth of black ash on wet peat or muck soils were calculated (table 3). A stand containing 80

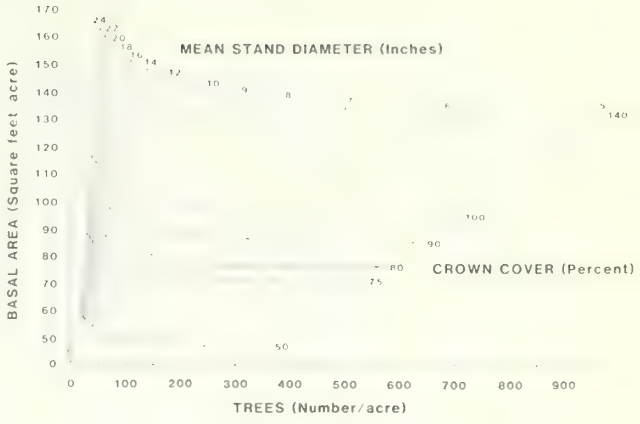


Figure 1.—*Stocking levels for black ash by crown cover, basal area, and trees per acre for specified average stand d.b.h. classes.*

square feet of basal area per acre in trees 5 inches d.b.h. and larger with a maximum tree size of 12 inches d.b.h. and a q factor of 1.3 was used to develop this uneven-aged size class distribution guide. Most second-growth stands require about three cyclic cuts aimed at achieving a desirable stocking and structure goal before they are fully regulated for sustained growth and yield.

On sites where $SI_{50} > 55$, the shelterwood system can be used to regenerate even-aged stands that are larger than 10 acres in size. Follow these guidelines for establishing regeneration with a shelterwood:

1. Select stands 15 to 18 inches d.b.h. or 110 to 130 years of age or older.

2. If advance black ash regeneration is present, mark from below to leave 50 percent crown cover of the best growing stock. Favor black ash regeneration by discriminating against other species in the overstory.

3. If advance black ash regeneration is absent, mark from below (preferably during a good seed year) to leave 75 percent crown cover. When black ash regeneration appears, open the overstory canopy to leave a 50 percent crown cover.

4. Remove the shelterwood overstory when the ground is frozen (preferably with more than 12 inches of snow cover) after the seedling reproduction attains a height of 2 to 3 feet (after 3 to 5 years). A minimum of 5,000 well-spaced seedlings and low sprouts should be left per acre.

Table 2.--Even-age stocking level table for black ash by percent crown cover, basal area, and number of trees per acre for specified d.b.h. classes [1/]

Stand d.b.h. (In.)	Crown cover (percent of 43,560 ft^2/A)									
	50 Percent		75 Percent		80 Percent		90 Percent		100 Percent	
	Trees	BA	Trees	BA	Trees	BA	Trees	BA	Trees	BA
	No./A	Ft^2/A	No./A	Ft^2/A	No./A	Ft^2/A	No./A	Ft^2/A	No./A	Ft^2/A
5	348	47.4	522	71.2	556	75.9	626	85.3	696	94.9
6	242	47.6	363	71.3	388	76.1	436	85.6	485	95.1
7	180	48.1	270	72.2	288	77.0	324	86.6	360	96.2
8	140	48.8	210	73.1	223	78.0	251	87.8	279	97.5
9	112	49.5	168	74.2	179	79.2	202	89.0	224	98.9
10	92	50.2	138	75.3	147	80.3	166	90.4	184	100.4
11	77	50.9	116	76.4	123	81.5	139	91.7	154	101.8
12	66	51.6	99	77.4	105	82.6	118	92.9	131	103.2
13	57	52.3	85	78.5	91	83.7	102	94.1	113	104.6
14	50	53.0	74	79.4	79	84.7	89	95.3	99	105.9
15	44	53.6	66	80.4	70	85.8	79	96.5	87	107.2
16	39	54.2	58	81.3	62	86.7	70	97.6	78	108.4
17	35	54.8	52	82.2	56	87.7	63	98.7	70	109.6
18	31	55.4	47	83.1	50	88.6	56	99.7	63	110.8
19	28	55.9	43	83.9	45	89.5	51	100.7	57	111.9
20	26	56.5	39	84.7	41	90.3	47	101.6	52	112.9
21	24	57.0	36	85.5	38	91.2	43	102.6	47	114.0
22	22	57.5	33	86.2	35	92.0	39	103.5	44	115.0
23	20	58.0	30	87.0	32	92.7	36	104.3	40	115.9
24	19	58.4	28	87.7	30	93.5	33	105.2	37	116.9

[1/] Expected black ash crown area = $-7.6483 + 3.8952$ d.b.h. $^{1.7974}$ Where d.b.h. is in inches; basis n = 37 forest grown trees that have a d.b.h. at least as large as the average stand d.b.h.; $R^2 = 0.89$. Values for the 20-inch and larger d.b.h. classes have been projected beyond our data base.

Table 3.--Desired stocking after cutting for sustained growth of black ash on organic peat or muck soil

	D.b.h. classes	Trees/acre	Basal area/acre
	Inches	Number	Square feet
Poles	5	69	9.3
	6	53	10.3
	7	41	10.8
	8	31	10.9
	9	24	10.6
Subtotal		218	51.9
Small saw logs	10	18	10.1
	11	14	9.4
	12	11	8.6
Subtotal		43	28.1
Total		261	80.0

Note: Stocking recommendations are based on a maximum tree size of 12 inches d.b.h., a q factor of 1.3, and a basal area of 80 square feet per acre for trees 4.6 inches d.b.h. and larger.

KEY TO RECOMMENDATIONS

Stand site index is less than 45	Manage to maintain wildlife habitat and water quality.
1. Stand site index is between 45 and 55	2
1. Stand site index is greater than 55	5
2. Soil is wet organic or muck	3
2. Soil is mineral with poor or impeded drainage	4
3. Stand basal area is less than 100 sq ft per acre	Review when stand reaches 100 ft^2/acre or is operable.
3. Stand basal area is more than 100 sq ft per acre	Make a partial cut (if operable) to recommended uneven-aged stocking level using upper d.b.h. of 12 inches (table 3).
4. Stand basal area is less than 100 sq ft per acre	Review when stand reaches 100 ft^2/acre.
4. Stand basal area is more than 100 sq ft per acre	Thin (if operable) to recommended even-aged stocking level (fig. 1 or table 2). First cut is to 80 percent crown cover. Subsequent cuts to 90 percent crown cover. Thin again after crown closure and lower branch mortality occurs on the crop trees.
5. Average d.b.h. (of trees 4.6 inches or more) is more than 18 inches	6
5. Average d.b.h. (of trees 4.6 inches or more) is less than 18 inches	7
6. Black ash reproduction is adequate (more than 5,000 stems per acre)	Make a shelterwood cut leaving 50 percent crown cover. Make a removal cut when regeneration is 2 to 3 ft tall (after 3 to 5 years).
6. Black ash reproduction less than 5,000 stems per acre	Make a shelterwood cut leaving 75 percent crown cover. Reduce overstory crown cover to 50 percent when stocking is adequate. Then make final removal cut as above in 6.
7. Stand basal area is less than 100 sq ft per acre	Review when stand reaches 100 ft^2/acre or is operable.
7. Stand basal area is more than 100 sq ft per acre	Thin (if operable) to recommended even-aged stocking level (fig. 1 or table 2). First cut to 80 percent crown cover; subsequent cuts to 90 percent crown cover.

EVALUATING SITE PRODUCTIVITY

Three site productivity classes are recognized in this key. Poor quality sites (SI_{50} less than 45) should be managed to maintain wildlife habitat and water quality. Medium quality sites (SI_{50} between 45 and 55) can be expected to produce some small saw logs (10 to 12 inches in d.b.h.). High quality sites (SI_{50} greater than 55) can be managed primarily for large saw logs (equal to or greater than 18 inches in d.b.h.). Site index, described as the average height of five dominant and codominant black ash trees in a stand at reference age 50, can be used to estimate the productivity of a given site for black ash. To determine site index select trees you would like to leave as crop trees. Suitable trees must be above average stand diameter; straight; single-stemmed; and without forks, serious diseases, or injuries. Fell each sample tree and measure the total tree height to the nearest foot. Then cut a 1- to 2-inch cross-section (disk) from just above (1 or 2 inches) ground line and count the rings on the disk. Use Carmean's (1978) polymorphic site index curves to determine the site index for each tree at reference age 50 and then calculate an average site index estimate for the stand (fig. 2).

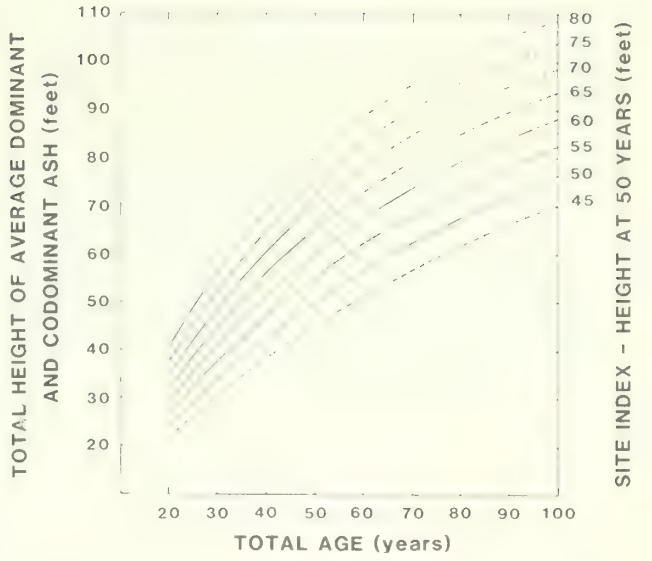


Figure 2.—*Site index curves for black ash in northern Wisconsin and Upper Michigan (Carmean 1978). Dashed lines indicate extrapolated data.*

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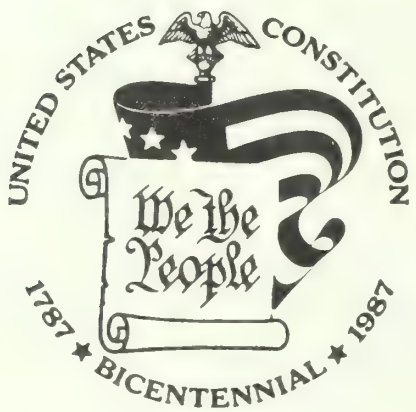
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